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# MECHANICS OF FORMATION OF ARCUATE MOUNTAINS

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## PART III

### THE FOLDING PROCESS STUDIED IN THE PROFILE—FORMATION OF SLIDES

*Imperfect plasticity of folding strata.*—Thus far we have discussed the flexures in rocks as though the plasticity of folding sediments were sufficient in all cases to permit without failure the development of both underturned and recumbent anticlines. Such a condition appears to be realized in nature only in the case of well-laminated rock formations, and it is proper here to consider a little more fully the subject of plasticity within compressed sediments under load and at somewhat elevated temperature.

At the surface of the earth so-called "hard rocks" behave like highly elastic bodies, and the degree to which this property of elasticity is modified by load has prevented a simple mathematical discussion of the subject of folding. Rudzki has stated perhaps as clearly as anyone the reciprocal relations of the properties of elasticity and plasticity in solid bodies.

> The elastic force with which the body resists the deforming force diminishes with time. The time which is necessary for the resisting force to fall to $\frac{1}{e}$ of its original value is called after Maxwell the relaxation time. A body is so much the more plastic the smaller the relaxation time. According to the

kinetic theory one may assume that all bodies are plastic to a certain degree, and that the differences have quantitative value. Obviously for room temperature and atmospheric pressure different bodies possess very different relaxation times. For steel the relaxation time may be some centuries; for wax, paraffine, etc., it is so small that the determination of the elastic constants by the usual static methods is difficult to carry out. Plasticity appears in some cases to be dependent upon the magnitude of the deforming force—it is larger and the relaxation time smaller the greater the force. Temperature has the greatest influence upon plasticity, the plasticity increasing with the temperature. Glass, which is at ordinary temperatures so brittle and breakable, shows distinct plasticity above 300° C. (order of magnitude of the relaxation time about a day).[1]

Quite obviously, where not centuries only but very much larger units of time may be involved in the folding process, the load which is necessary to produce plasticity sufficient for folding may be very much less than that indicated by experiments.[2]

There is, however, a way of looking at the subject of potential plasticity as it relates to folding strata, which will give us an insight into the conditions under which failure may occur. The different parts of a fold are subject to internal strains which in the anticlines of relatively late stage differ by large amounts. It therefore occurs that the period covered by the evolution of a fold may be sufficiently long to permit the resisting forces within the strata to fall, and local strains to occur without failure except at critical points of maximum deformation. In this event failure will occur at the locus of maximum deformation much as it would in a relatively elastic body, even though the remaining portion of the arch adjusts itself to the stress conditions like a truly plastic body. Our problem is, therefore, to discover the locus of maximum strain in a growing anticline.

*Contrasted cases of isotropic and anisotropic strata—control of internal strains by lamination.*—The problem of representing the system of internal strains within a developing anticline is complicated by the variations in texture which characterize rock formations. There are, on the one hand, formations such as heavy limestone

[1] *Physik der Erde* (author's German translation), Leipzig, 1911, pp. 232–33.

[2] See in this connection, F. D. Adams, "An Experimental Contribution to the Question of the Depth of the Zone of Flow in the Earth's Crust," *Jour. Geol.*, XX (1912), 97–118; L. V. King, "On the Limiting Strength of Rocks under Conditions of Stress Existing in the Earth's Interior," *ibid.*, pp. 119–38.

or dolomite members which are largely devoid of lamination planes and hence to be regarded as not only nearly homogeneous but approximately isotropic as well. Rather generally, however, sediments are characterized by more or less numerous planes of ready separation (lamination) parallel to the original upper and lower surfaces of the formation, and such formations are to be regarded as essentially anisotropic with a minimum of cohesion at right angles to the lamination planes. The movements of particles due to internal stresses are of necessity guided by these surfaces, since the adjacent thin layers permit of the differential sliding (shearing) motions generally described as accommodation between layers. The more perfect the lamination, the more readily does the stratum rise to form an arch. On the contrary, any tendency toward cross-fractures in the strata, such as are generally to be found in shales, lowers the strength of the arch and brings about its failure. The significance of lamination in this connection may be the better appreciated by considering the bending of two rods, one of wood cut parallel to the grain, and the other shaped from some isotropic substance like glass or wax. The rod cut parallel to the grain possesses large cohesion in the direction necessary to resist strong tension upon the convex surface when bent, but the least cohesion in the direction to facilitate the necessary adjustment by shearing between parallel longitudinal layers within the mass.

*Shearing movements within an anticline for the contrasted cases of isotropic and of well-laminated strata.*—For the case of laminated strata we may study the internal strains within an anticline by means of a simple experiment. Two exactly similar piles of paper were taken, each some two feet or more in length, two inches in width, and one inch in thickness. Upon the long edges of these piles series of tangent circles were carefully drawn in ink, each with its vertical diameter. The circle was chosen as guide form, both because it is the figure of highest symmetry and favors no one direction more than another, and because conglomerate pebbles, by rudely simulating in some cases this form in section, have sometimes preserved a valuable record of deformations within anticlinal arches.

Thus prepared, one of the piles was bent into the form of an unsymmetrical anticline (Fig. 30), the other being preserved as it

was for purposes of comparison and to note the measure of crustal shortening in anticline evolution. Observing now the deformations

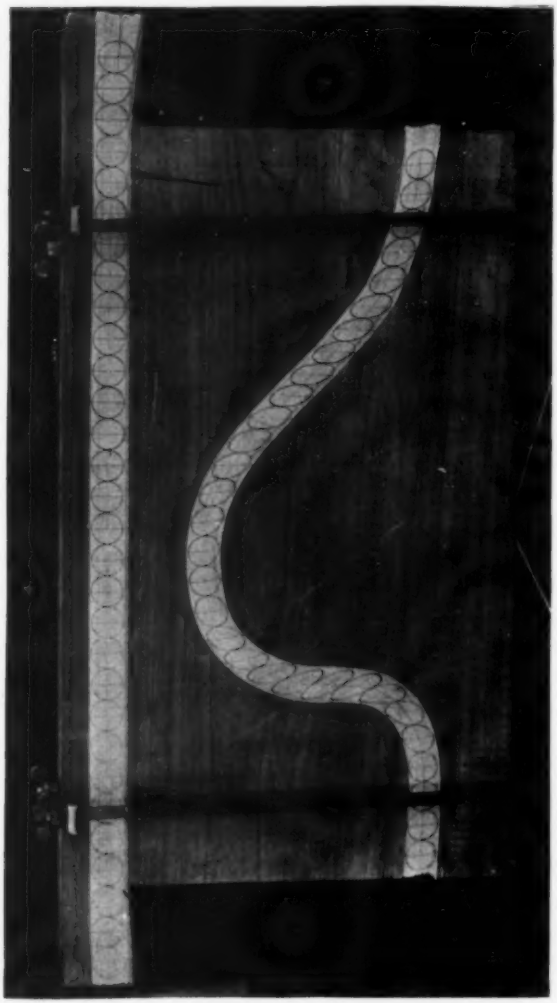

FIG. 30.—Model to illustrate the internal strains which are developed within a stratum in the process of folding

of the guide circles, it is found that slight deformation only has occurred in the neighborhood of the crest of the anticline and near

the trough of the neighboring syncline (a slight elongation of the vertical diameter). Elsewhere at all points on either side of the points of inflection of the fold a more complex deformation has taken place, for the circles have been transformed into more or less elongated obovate figures with the greatest elongation at the

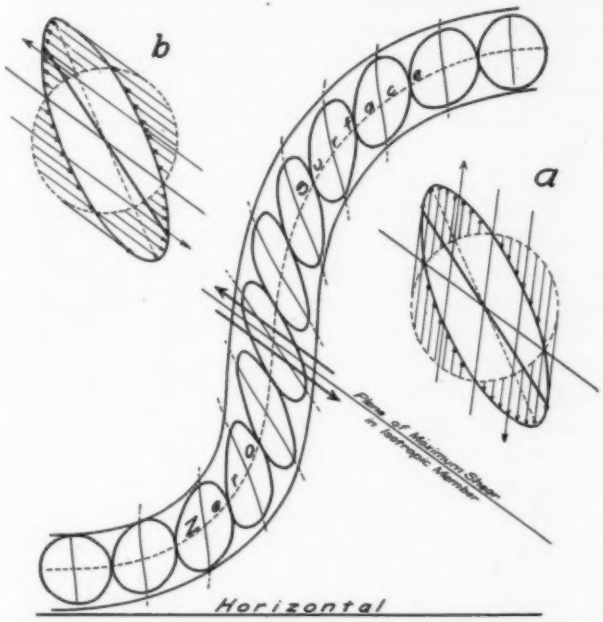


FIG. 31.—Steeper limb of the anticline produced from a pile of paper to show the deformed guide circles (traced): *a*, enlarged diagram at the point of inflection to show the actual migrations of particles by shearing movements parallel to the lamination; *b*, enlarged diagram of the deformations at the point of inflection if the stratum bent had been from isotropic material.

points of inflection. Comparing the upper and flatter with the lower and steeper limb of the anticline, we find that deformation has been greater in the steeper limb, and since we are seeking the locus of maximum deformation we will examine this limb somewhat more in detail (Fig. 31).

Above the point of inflection of the limb it is to be noted that the originally vertical diameters of the guide circles now diverge

upward, thus indicating that there has been tension upon the convex side and compression upon the concave side of the stratum. These relations are reversed in the synclinal portion. The points of inflection of the double curves into which the guide circle diameters have been transformed define a surface within the stratum which has been neither expanded nor contracted and is known as the "zero surface." This surface is in the true anticline section below, and in the syncline section above the median surface of the stratum.[1]

*Earlier failure in anticlines of unlaminated or poorly laminated strata.*—At the point of inflection in the steeper anticline limb, deformation is clearly at a maximum, and failure, if it is to occur, will be located here. The enlarged diagrams *a* and *b* of Fig. 31, which set forth the original and the deformed conditions of the guide circles at this critical point, show that there are two exactly similar common diameters to the circle and ellipse and that the observed deformations might have taken place through migrations of individual particles either in one or in the other of two ways, dependent upon which offered the minimum of resistance. Obviously the slight cohesion to be overcome by the shear of the paper laminae over each other has determined that in the case of our experiment—a well-laminated (anisotropic) stratum—adjustments shall take place parallel to the laminae, for which reason failure is little likely to result until a late stage of the anticline has been evolved. Had our stratum been, on the other hand, without lamination planes (isotropic), adjustments would have taken place in the sense of diagram *b*, and failure would have occurred parallel to the other common diameter in the figure as an application of the principle of greater weakness on the section of minimum area.

As an application of these considerations we find that unlaminated strong members like limestone fail in the process of anticline

[1] When well-laminated rock formations lie beneath a competent member of heavy massive rock like limestone, the strong tendency to shear along lamination surfaces may result in a complicated puckering of the laminated inferior formation even though the arch in the competent formation remains comparatively simple. This phenomenon so often observed in folded mountain regions and reproduced by Willis in his experiments (*The Mechanics of Appalachian Structure*, Pl. 90) involves an attenuation of the puckered laminae. It is also to be observed that the puckerings or plications are concentrated in the crown of the anticline where tension in the stratum protected may supply the space necessary for duplication by plication.

formation at an early stage and near the point of inflection of the lower limb; whereas anticlines in tough laminated strata persist until strongly underturned and then fail only after excessive stretching of the under limb and at an angle with the base which would indicate that the adjustments of individual particles were nearly or quite parallel to the laminae. These contrasted examples illustrate respectively Willis' types of "break thrusts" and "stretch thrusts"[1] (Fig. 32).

The second arch within a series of anticlines may in its turn fail in a manner similar to the first, and others of the series in succession; thus yielding a series of slices which in early stages at least dip away from the active force of compression and are described as "imbricated structure" (*Schuppenstruktur*, Fig. 25, *B*).

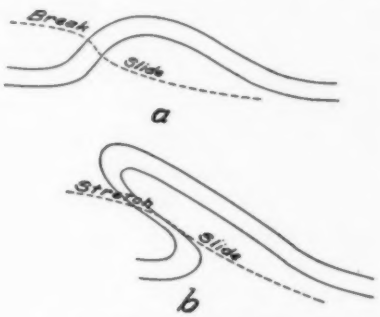


FIG. 32.—Diagrams to illustrate failure in anticlines; *a*, in an isotropic member such as limestone—break slide, or "break thrust"; *b*, in a tough laminated member such as schist—stretch slide, or "stretch thrust."

*Slides and their modified direction after leaving the competent member.*—The names in most general use, or at least in longest use, for the surface of failure within an anticline are "thrust" and "overthrust." The former is in every way undesirable because so likely to be confused with the same term in general use in mechanics for an active force; while the latter term is further objectionable in that it assumes that the active force responsible for the surface of failure operated from above and behind the anticline. Suess's term "sole" (*Sohle*), now employed by many, is without these objections, but the word "slide" recently suggested by Bailey[2] is perhaps even better.

[1] Willis, *op. cit.*, p. 223.

[2] E. B. Bailey, "Recumbent Folds in the Schists of the Scottish Highlands," *Quart. Jour. Geol. Soc.*, LXVI (1910), 593.

With the advent of failure in an anticline a new resolution of the active force of compression takes place with components parallel and perpendicular to the slide, movement is facilitated, and the potential energy of the system of stresses falls in consequence. The acute angle which the active force makes with the slide, and the reduced resistance opposed to shear along that surface, alike favor the underthrusting of the lower portion of the severed limb of the anticline beneath the upper (Fig. 25, *A*).

In the case of a well-laminated formation where a "stretch slide" has occurred, the slide, being nearly or quite parallel to the lamination, is extended along the lamination planes on either side within the inferior and superior formations of the series. Since the anticline contains the most steeply inclined of the layers, the dip of the slide is progressively flattened as it passes out from the anticline in either direction. For the case of a "break slide" within massive sediments, the entry into these surfaces of least resistance to slide may be less easily made but in either case a local swell of the slide surface may result. Both the low dip angles and the undulations of slides are well established by observation in many districts. The entry of the slides into the bedding planes of the formations tends to make of the severed rock formations a series of flatly disposed and widely extended slices capable of individual lateral migrations in mass, which in view of their position relative to the active force should be described as "underthrusting."

*Underthrusting of rock slices separated by slides simulated in experiment.*—If we represent the relatively thin slices, which are separated by slides dipping at low angles away from the active force, by a series of overlapping cards resting upon a stretched rubber sheet, and the unfolded neighboring sections on either hand by similar cards laid end to end as essentially continuous and hence relatively rigid sections of strata (Fig. 33), we may illustrate the underthrusting of the strata if we allow the rubber sheet to contract through releasing the tension upon it. With excessive underthrusting the cards are piled into a low dome elevated by the underdriving of the cards in proportion as the contraction of the rubber sheet has been large. It may happen also that the cards above and at the front dip forward and overlap at the forward end

those lower in the series. This latter feature is a well-known peculiarity of the *Deckenbau* upon the northern border of the Alps (Fig. 34), and it is clearly favored by the sinking crowns of recumbent anticlines.

*Formation of drag folds and listric surfaces at the front of underthrust slices.*—The new system of stresses, which is inaugurated with the process of underthrusting, may lead to the formation of secondary folds and eventually to secondary slides within the mass beneath which a slice is driven. This driving-in of one slice after another not only produces friction breccia ("mylonite") at the contacts,

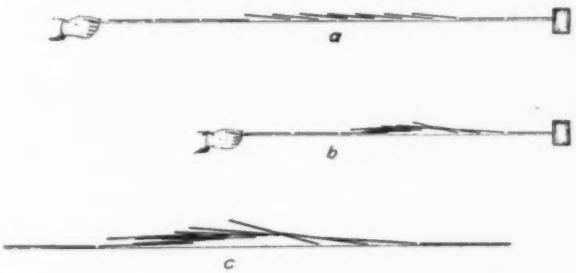


FIG. 33.—Diagram illustrating underthrusting of slices

but pushes upward and tends to fold under the frontal portion particularly of each underdriven slice. The active force of compression being still directed from in front of the folds and below, the "drag folds" which result ( Figs. 34 and 35) should be underturned from the front, attenuated in the underturned lower limb, and eventually underthrust in that limb, much as are the folds of larger order of magnitude upon whose fractured remnants they have been superimposed. Instead, however, of being extended for any long distance on bedding planes, these secondary slides should here converge into the subjacent major slide. The shovel-like curvature which is so generally characteristic of them has suggested the name "listric surfaces" applied to them by Suess[1] (Fig. 35, Rigihochfluh and Mythen, and Fig. 37).

[1] *Listrische Flächen* (*Das Antlitz der Erde*, III, Pt. II, p. 612; *The Face of the Earth*, IV, 536).

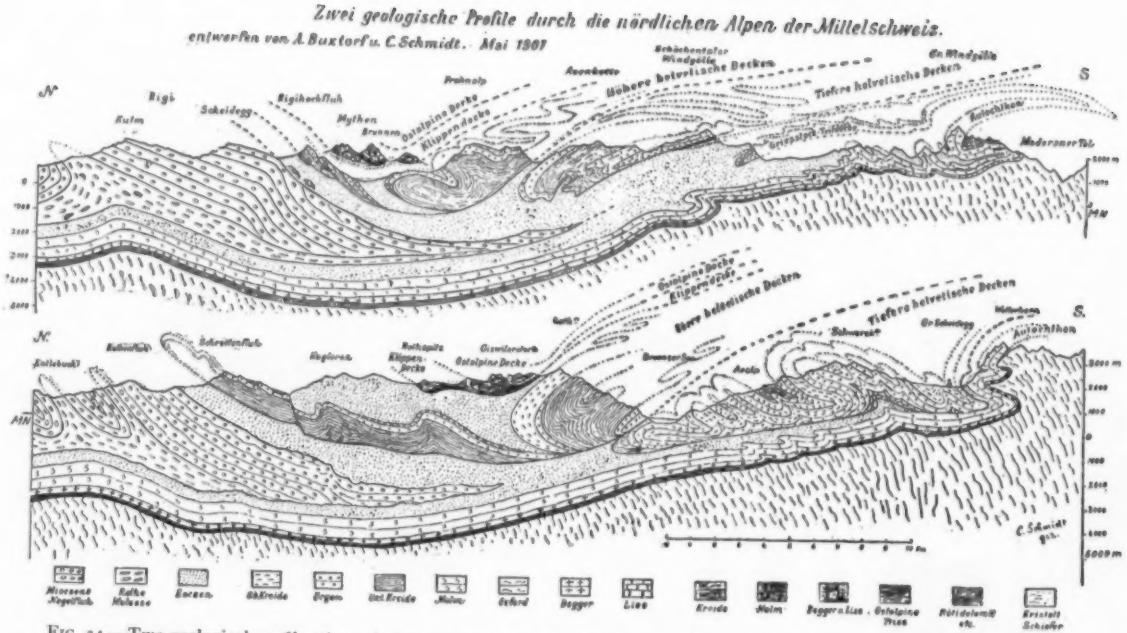


FIG. 34.—Two geological profiles through the northern Alps in middle Switzerland which show the characteristic frontal overlapping of slices and the formation of drag folds and listric surfaces (after Buxtorf and Schmidt).

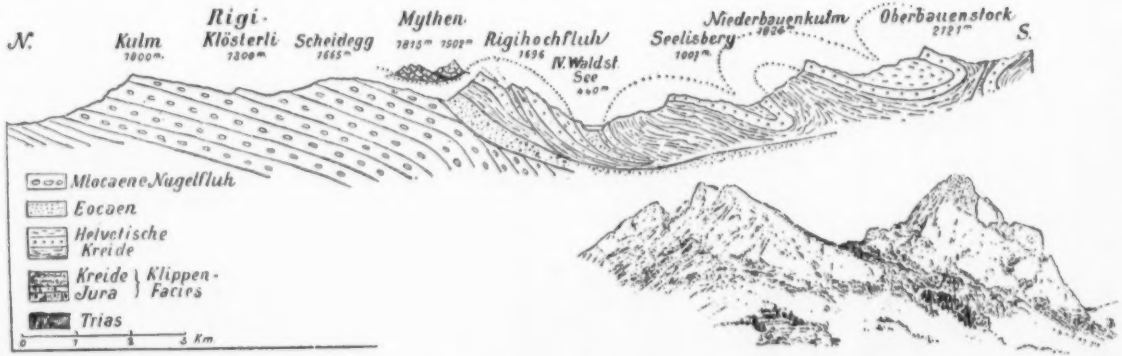


FIG. 35.—Profile of the front of one of the slides in the northern Alps to bring out the relationship of major slides to listric surfaces. At the right a sketch of the Mythen (after Tobler, Buxtorf, and C. Schmidt).

The relationship to each other in position of the listric surfaces which are produced by drag suggests the peculiar shearing surfaces which are seen at the snouts of some glaciers, save only that the distribution of forces is essentially reciprocal. It is the *upper* layers of the glacier which are pushed *forward* and *override* the lower layers held back by friction (Fig. 36). As a consequence, and as already pointed out (*ante*, p. 181), it is the upper limb of each fold rather than the lower that here becomes attenuated.

Extended slides within folded strata of mountains would appear to be greatly favored by the presence of a weak formation immediately above the competent member, this weak formation acting, so to speak, as a lubricant for the slide surface. It is no doubt significant that in the Alps the weak Flysch overlies the Helvetian limestones, for this yielding formation underlies one great slide after another in the series —"*Wildflysch*" (Figs. 34 and 35). It may also be of significance that within the same region the formation against which the slides rise at the front with the greatest development of listric surfaces is the hard *Nagelfluh* conglomerate, which has a local development only upon the northern margin of the Alps, and opposite whose areas rise the largest accumulation of rock slices.

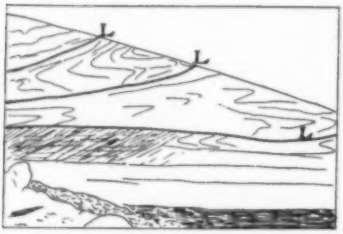

FIG. 36.—Slide surfaces in a glacier snout (after T. C. Chamberlin).

Examination of numerous profiles which include rock slides indicate pretty clearly that portions of the indriven slices have sometimes become involved in the complex of wedges at the front of each overlying slice (Fig. 37). Sections of the Belgian coalfield (Fig. 37, *e* and *f*) and of Buffalo Mountain[1] (Fig. 38) may be cited as examples.

## SUMMARY

The Alps represent the type of Asiatic mountain arcs, and hence in explaining their tectonics deductions from Asiatic studies are

[1] Arthur Keith, "Roan Mountain Folio, Tennessee–North Carolina," *Folio 151, U.S. Geol. Surv.*, 1907, p. 9.

to be utilized. Arcuate structure representing a reduplication of strata in recumbent and ruptured folds requires that the duplicated material shall have migrated centripetally from outside the arc and implies that the mass within is relatively the more rigid.

The arcuate ranges of Asia, regarded not individually but as a system, favor the conclusion which we have reached of centripetally distributed thrusts directed toward the center of the system: (1) by their plan of arrangement; (2) by the position of the relatively rigid area (Angara Land); (3) by the greater geological age of the central, and the newer formation of the peripheral arcuate ranges; and (4) by the present locus of intense volcanic and seismic activity along the outer margin.

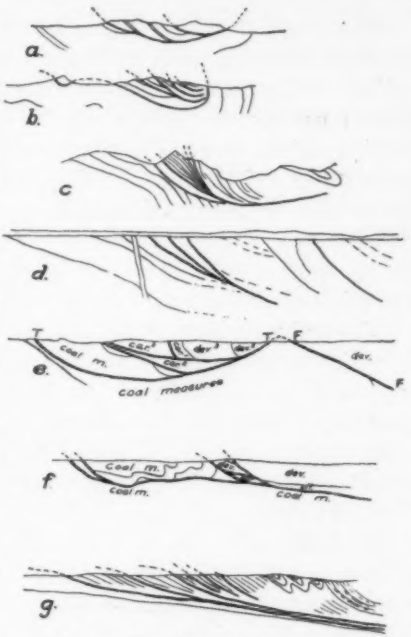


FIG. 37.—Examples of listric surfaces developed at the forward end of major slides: *a* and *b*, Buffalo Mountain, southern Appalachians (Keith); *c*, Rigihochfluh, northern Alps (Tobler and Buxtorf); *d*, Belgian coal-fields from St. Éloi to St. Léon (Briart as reproduced by Suess); *e*, Belgian coal-field at Fontaine-l'Évêque (Briart and Suess); *f*, the same near Denain and Anzin (Bertrand and Suess); *g*, North-central Carpathians (Uhlig). For better comparison all sections have been made to look north, northeast, or east.

FIG. 38.—One of the sections through Roan Mountain in the southern Appalachians (after Keith).

The ocean floors are today for the most part sinking and represent the great areas of dispersal of thrusts toward the neighboring continents, and mountain arcs should therefore be convex toward oceanic depressions. If in the past during mountain-making periods ocean floors have represented areas of dispersal of thrusts, the position and the orientation of the earlier arcs should be an expression of the former areal relations of the continental pedestals and the ocean floors. For the continent of Asia this theory appears to be borne out by what we know of continental evolution within the principal mountain-making periods.

The active force (thrust) which produces rock folds, instead of operating from behind and above the anticline, as so generally supposed, is applied below and in front. Continuation of the process yields therefore not "overturned" and "overthrust," but *underturned* and *underthrust* flexures. Applied to the Alps, this requires that the main active force concerned in their folding came from the northwest, instead of the southeast, as generally assumed.

Anticlines arise first upon that side of the folding area which is toward the direction from which the force comes. In strong or competent members anticlines lift a portion of the load from arched underlying formations, and this portion, regarded as a percentage of the total load upon the arch, is at first small, but afterward rises steadily and rapidly up to the stage of underturning, after which it rapidly diminishes.

With the underturning of an anticline a new distribution of stresses is inaugurated, as a result of which a second anticline may develop behind the first and subsequently others in succession but of steadily diminishing dimensions until the series comes to an end. Thus it comes about that while the arcs in the order of their age develop from within outward in the series as the continental area becomes extended peripherally, the *folds* (*anticlines*) *within any arc* are developed in order of age from without inward (Fig. 39).

With the stage of underturning a new couple composed of vertical forces enters and tends to rotate the underturned arch, not forward as before, but downward; and if the competent member is overlaid by a weak formation, the crown of the arch will be left without sufficient support and will sink to form a "plunging crown." If

supported by a strong formation this will not occur, but it will in any case eventually be rotated as a whole about its base and form a normal recumbent anticline.

Subsequent to the stage of underturning of the anticline, the active force of compression tends to reduce the volume of the included roll of the inferior strata with the effect of stretching and attenuating the under limb of the anticline in the competent member. Attenuated upper limbs of anticlines, though unknown in

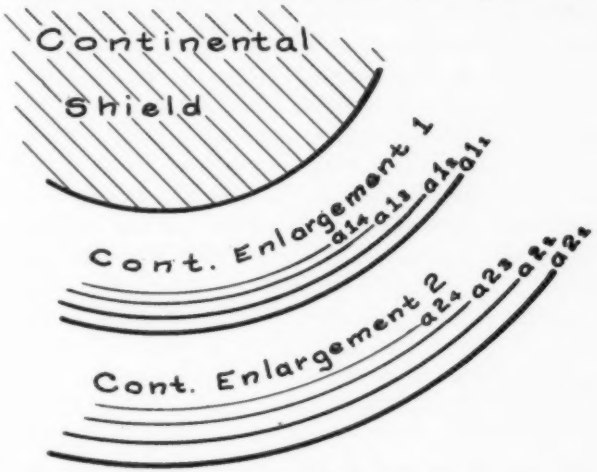


FIG. 39.—Schematic diagram to illustrate the order of development of mountain arcs from within the series outward, and the development of anticlines within each arc from without inward.

rock folds, are illustrated by the ice-folds within glacier snouts, where they are due to true overturning movements.

The partial relief of load from the inferior formations beneath the competent member in the arch may make possible under suitable conditions of temperature a local development of a magma macula; and the tendency to reduction of volume with continued underturning of the anticline supplies an efficient cause of the elevation of such lava toward the earth's surface. Association both in time and in place of volcanoes of the Pacific type with growing mountain arcs would thus be accounted for.

Backfolding occurs where relatively competent rock formations are locally replaced by weak material, or where a surface of disjunction transects the formation. The backfold develops in front of and eventually above the zone or surface of weakness.

The evolution of an anticline to late stages of underturning is directly determined by the measure of lamination of the competent member and the toughness of the laminae. Relatively strong rocks devoid of lamination fail by cross shear ("break slide") and at a much earlier stage of the anticline than tough well-laminated rocks which, on the contrary, fail on disjunctive surfaces which are nearly or quite parallel to the lamination ("stretch slide").

After failure of an anticline has occurred, a new resolution of the external forces takes place with components parallel and perpendicular respectively to the surface of failure (slide); this surface tends to be extended in either direction along surfaces of least resistance—usually bedding planes—and is thus flattened as it recedes from the competent arch. With the advent of the slides, migrations of the severed parts of the fold are greatly facilitated, and movements of the rock slices take place in such a sense that the lower are driven in beneath the upper—underthrusting.

The large friction on slides incident to underthrusting is reduced by a weak formation superior to the competent member. Friction breccia (mylonite) generally marks the position of the slide which develops special features at its forward end. Here are found secondary folds (drag folds) and secondary slides (listric surfaces), the former being underturned and attenuated in the underlimb, while the latter are concave upward (shovel-shaped) and converge into the major slide below. The lower of two contiguous slices may be ruptured and involved in the complex of curved wedges at the front of the slice immediately above.

September 15, 1913

# THE STRENGTH OF THE EARTH'S CRUST

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## PART III. INFLUENCE OF VARIABLE RATE OF ISOSTATIC COMPENSATION

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### INTRODUCTION AND SUMMARY

The work of Hayford on the deflections of the vertical, and of Hayford and Bowie on the anomalies of gravity, has supplied the geodetic data from which future work must start. As an initial basis to guide their work, it was desirable to assume the hypothesis that isostatic compensation was complete for each topographic irregularity, giving local compensation, and that it was uniformly distributed to a constant depth. The actual results may then be compared to this ideal of local, uniform, and complete isostasy and the degree of departures noted, as given by residuals and anomalies.

In Part II the subject of the regional distribution of compensation was examined and the conclusion was reached that the crust was sufficiently rigid to bear such mountains as Pikes Peak without requiring special compensation below. In general it is thought compensation in mountain regions extends to more than 200 km. and in some regions to more than 400 km. In this part are considered the effects of variations in the vertical distribution of

compensation and the degree to which such variability may give rise to anomalies and residuals without signifying incompleteness of compensation in the column as a whole or regional departures from isostasy.

In order to show the limits of variation in density which are to be expected, the specific gravity of rocks is first considered. Figures are computed for the mean specific gravity of igneous rocks and the three types of sediments. It is shown that the range of variation is an important factor. Under the subject of the relations between mass and the distance of mass upon anomalies, the effects are computed of unit masses at various depths and extending various distances.[1] This lays the basis for considering the influence of the specific gravity of the surface geologic formations upon the difference between the mean anomalies for stations on pre-Cambrian and those on Cenozoic areas. It is found that the greater density of the older rocks accounts for a part and another part is accounted for by their resistance to erosion. This still leaves, however, large outstanding regional variations not related to surface geology or topography and requiring some other explanation. To that end criteria are discussed for the recognition and separation of the effects of mere variable vertical distribution of compensation on the one hand, from partial regional absence of isostasy on the other. It is concluded from the application of these criteria that the anomalies are in large part caused by real regional departures from isostasy extending over broad areas. The results are thus

[1] A paper by Gilbert has recently appeared entitled "Interpretation of Anomalies of Gravity" (*Part C, Professional Paper 85, U.S. Geological Survey*, 1913). This did not reach the present writer until after Parts III and IV of this article were in galley proof, so that his results cannot be as fully interwoven into the discussion as would otherwise have been the case. On pp. 30, 31, Gilbert considers the interpretation of anomalies on the assumption of vertical heterogeneity of the crust and shows clearly that moderate variations of density in a vertical direction could explain them. From this he infers that the anomalies may be due in part to such irregularities. This is the topic which is treated in Part III of the present article under the title "Interpretation of Anomalies in Terms of Mass and Depth." The method of reasoning is somewhat different, but although the conclusion reached is the same, the calculations given here are intended to bring out in addition the limitations of area and mass within which that principle applies. It is concluded as a result of the following examination of the evidence that although vertical variations of density are a real cause they are not the major cause of anomalies.

confirmatory of those reached in Parts I and II. In addition, however, it appears that there is a regional departure from isostasy of two orders of magnitude. Loads under the mean value, giving anomalies below 0.018 to 0.020 dyne and estimated to be equivalent to about 750 feet of rock, can be carried over regions of irregular boundaries ranging up to from 1,000 to 2,000 km. across. Over such a broad region the anomalies are of one sign except for some smaller well-defined sub-areas of high anomaly within them which may or may not have the same sign. These smaller areas give a higher order of stress magnitude and are of more restricted dimensions, being measured in hundreds of kilometers. They range in magnitude of anomaly to several times the value of the mean and the equivalent radii of their areas probably average 100 to 200 km. The deflection residuals show by the limits of the areas of like sign that the regional variations of gravity anomalies of this areal magnitude extend over the whole country, but where the amounts of the local anomalies are less in value than the mean they are largely masked on the contour map of gravity anomalies (Fig. 5), because of their superposition upon the broader areas. Presumably a multiplication of the gravity stations would bring them to light as undulations in the contours which show the regional departures.

A final conclusion on the subject of the variable vertical distribution of mass must, however, be deferred until consideration has been given to a hypothesis advanced by Gilbert in his recent paper, that heterogeneities of mass below the zone of compensation may be the cause in major or minor part of the apparent departures from isostasy. This is a subject too large to be considered in this third part of the present article, but it is planned to investigate it in Part V by a method of graphic analysis devised for determining the depth of excesses or deficiencies of mass.

## THE SPECIFIC GRAVITY OF ROCKS

For a knowledge of the variations of density likely to occur in rocks it is important to know the range in specific gravities shown by the common rock types. The following figures, except those for shale, are taken from Pirsson's *Rocks and Rock Minerals:*

TABLE V

| Rock | Specific Gravity |
|---|---|
| Granite | 2.63–2.75 |
| Syenite | 2.6 –2.8 |
| Diorite | 2.8 –3.1 |
| Dolerite | 3.0 –3.3 |
| Limestone | 2.6 –2.8 |
| Sandstone | 2.5 –2.7 |
| Shale | 2.4 –2.8 |
| Slate | About 2.8 |

[The specific gravity of shale, although the most abundant of sedimentary rocks, is not given in any of the manuals of geology, but Professor Hobbs, who has read much of this manuscript and to whom the writer is indebted for a number of suggestions, has called attention to the above figure as given by Trautwine. In general, Trautwine and Kent give a somewhat greater range in specific gravities and they average a little lower than those here given. The figures from Pirsson, however, probably express more closely the relation of the petrologic type and the more compact states of rocks to their density. They are, therefore, thought to be better representative of the lithosphere.]

These figures show that notable departures may occur from the mean density of the outer crust and suggest furthermore that 2.67, the mean density used by Hayford, is lower than the actual mean. A more thorough analysis of the subject is therefore needed.

The abyssal igneous rocks and metamorphic rocks are almost without pore space. The sedimentary rocks, on the other hand, possess abundant pore space in their unconsolidated states, very little in their compact states. The latter is the usual mode of occurrence in the older geological formations. The density is therefore a function of both mineral composition and porosity. The chemical compositions of the several rock types and also of the average sediment and the average igneous rock are well known. The mineral compositions are less well known but may be computed with a fair degree of accuracy; the densities, on the contrary, are least commonly reported and the mean densities of the rock types cannot in consequence be closely determined by averaging numerous determinations, as is done for the chemical compositions. It seems desirable, therefore, to compute the densities of the rock types from the chemical and mineral compositions, combining this with the densities of the individual minerals, making a separate correc-

tion for the porosity factor. The data, assembled from various sources[1] and subjected to computation, give the following results:

TABLE VI

COMPOSITION OF AVERAGE IGNEOUS ROCK

| Mineral | Percentage |
|---|---|
| Quartz | 12.0 |
| Feldspars | |
| Orthoclase molecule | 22.0 |
| Albite molecule | 29.5 |
| Anorthite molecule | 8.0 |
| Hornblende and pyroxene | 16.8 |
| Mica | 3.8 |
| Accessory minerals | 7.9 |
| | 100.0 |

TABLE VII

COMPOSITION OF AVERAGE SEDIMENTS

| Mineral | Shale | Sandstone | Limestone |
|---|---|---|---|
| Quartz | 22.3* | 66.8* | 2.0 |
| Feldspars | | | |
| Orthoclase | 18.0 | 7.0 | 0.3 |
| Labradorite | 12.0 | 4.5 | 0.1 |
| Clay | 25.0† | 6.6† | 2.0‡ |
| Limonite | 5.6 | 1.8 | 0.6 |
| Calcite } Dolomite } | 5.7 | 11.1 | 55.0 / 35.0 |
| Other minerals | 11.4 | 2.2 | 5.0 |
| | 100.0 | 100.0 | 100.0 |

* The total percentage of free silica.

† Probably sericite in part; in that case the feldspar figure becomes lower.

‡ Two per cent clay takes 0.79 of $Al_2O_3$. This requires that most of alkalies form non-aluminous hydrous silicates or that 0.81 $Al_2O_3$ as given by Clarke is too low.

It is thought that the densities without porosity are figures of some value for geodetic computations. The chief error in making the final estimates is in connection with the lack of accurate knowledge regarding the pore space of those sedimentary rocks not used

[1] For data on the mean chemical and mineral composition of rocks see F. W. Clarke, "Data of Geochemistry," *Bull. 491, U.S. Geol. Surv.*, 1911, pp. 30, 31. For specific gravities of minerals see Pirsson, *Rocks and Rock Minerals*, 1908, p. 31; also Dana, *Mineralogy*. For a discussion of pore space see Fuller, "Total Amount of Free Water in the Earth's Crust," *Water Supply Paper No. 160, U.S. Geol. Surv.*, 1906, pp. 59–72.

as building stones, but this affects appreciably the density of only a superficial layer and chiefly of the youngest deposits.

The ratio of shale, sandstone, and limestone in the average sediment in percentage is, according to Mead,[1] shale 80, sandstone 11, limestone 9. The ratio of average porosities in percentage is, according to Fuller,[2] crystalline rocks 0.2, shales 4, sandstones 15, limestones 5. The figure given by Fuller for shale rests upon a single determination of 7.8 per cent by Delesse, and is averaged in by Fuller with slate. Eight per cent porosity will here be assumed as probably a better estimate. This gives the porosity of the average sedimentary rock as 8.5 per cent. The pore space may be taken, following Fuller's estimate, as half filled with water.

From these data the specific gravities are computed to be as follows:

TABLE VIII

SPECIFIC GRAVITIES COMPUTED FROM MINERAL COMPOSITIONS

| Rock | No Pore Space Allowed | Pore Space Half Filled with Water |
|---|---|---|
| Average igneous rock.. | 2.80 | 2.80* |
| Shale..... | 2.69 | 2.51 |
| Sandstone..... | 2.67 | 2.35 |
| Limestone..... | 2.76 | 2.64 |
| Average sedimentary rock..... | 2.70 | 2.50 |

*The same figure as used by Chamberlin and Salisbury, *Geology*, I (1904), 538; also by Pirsson, *Rocks and Rock Minerals;* also by G. H. Darwin as the density of the outer crust.

Where Cenozoic deposits occur in thickness, they are considerably compacted except at the surface, but still the mean specific gravity, owing to the abnormal pore space and deficiency in limestones, is doubtless less than 2.50; 2.45 may be taken. It is probable, on the other hand, that the Paleozoic rocks on the whole have somewhat less pore space than this average, especially as the porosity figure for sandstone rests mainly upon determinations for brownstone, a rather porous type; 2.55 may then be taken as the average for Mesozoic and Paleozoic formations. The pre-Cambrian

[1] "Redistribution of the Elements in the Formation of Sedimentary Rocks," *Jour. Geol.*, XV (1907), 238–56.

[2] *Loc. cit.*

rocks contain both igneous and sedimentary formations, but the considerable iron ore and metamorphic nature would bring the specific gravity of the sediments somewhat above the average of 2.70 for non-porous sediments. Broad areas of pre-Cambrian probably range therefore between 2.75 and 3.00 in specific gravity. More limited areas, because of a predominance of granite and quartzite, may range as low as 2.70. About 2.67, however, would be a minimum.

As these are merely averages it is better in basing calculations upon them to assume a certain range in density for each figure and to obtain thus a knowledge of the influence of reasonable variations upon the results. The data may then be tabulated as follows:

TABLE IX

ESTIMATED MEAN SPECIFIC GRAVITIES OF GEOLOGIC FORMATIONS

| | |
|---|---|
| Pre-Cambrian | 2.75–2.80 |
| Paleozoic and Mesozoic | 2.50–2.60 |
| Cenozoic | 2.40–2.50 |

The range in these specific gravities shows the necessity of considering them in all refined calculations on the anomalies of gravity. In place, however, of using a mean density figure for all stations on formations of a certain geologic age, it would be of much more value to have measurements of the actual surface densities occurring in each area; also estimates by geologists, based on geologic structure and these surface measurements, of the densities extending to the base of the sedimentary rocks of each locality.

It seems probable from the mean density of 2.80 obtained for igneous rocks that the density of 2.67 used by geodesists for the mean density of the zone of compensation is too low. If any variation from the average composition takes place with depth within the limits of 76 miles, it is likely to be a variation toward more basic and heavier rocks. Assuming, however, an average uniformity of chemical composition, the opposing effects of temperature and pressure remain to be considered. Using the coefficient of expansion of the average igneous rock computed by W. H. Emmons,[1] 0.000.019.9 for 1° C., and a temperature gradient of

[1] Chamberlin and Salisbury, *Geology*, I (1904), 547.

1° F. for 60 ft. in depth, gives an aggregate expansion of 3.6 per cent to the outer 76 miles. Using 6,500,000 as the modulus of cubic compressibility of the average rock in pound-inch units[1] gives a total compression of 3.7 per cent to the outer 76 miles due to pressure; that is, the volume effects of heat and pressure practically offset each other within the zone of isostatic compensation. Therefore 2.80 appears to be the lowest mean figure which should be taken. The use of 2.67 as a mean figure requires for isostatic equilibrium a density of but 2.60 extending to a depth of 76 miles under land 3 km. high, a figure lower than the specific gravity of granite.

### INTERPRETATION OF ANOMALIES IN TERMS OF MASS AND DEPTH

Suppose that the zone of isostatic compensation is not of uniform density under any one station, but contains masses of variable density irregularly distributed. Let these masses be of considerable thickness and area as compared to the depth of the zone of compensation. Suppose that the topography is so adjusted to the aggregate density that the pressures are everywhere equal at the bottom of the zone of compensation. Abnormally light masses would then have to be balanced by abnormally heavy masses in the same column. There would still be deflections of the vertical and anomalies of gravity because gravitation varies inversely with the square of the distance, the upper and adjacent masses of abnormal density affecting the station more than those more distant ones of opposite abnormality lying vertically below the upper. The residuals from deflection and gravity measurements would under such an arrangement measure strains within the outer crust but not upon its bottom. The strains, if produced by abnormalities in the upper parts of the crust, would further be proportionately smaller and yet give rise to residuals of a certain magnitude than if produced by abnormalities in the lower parts of the crust. This aspect of the problem must be investigated before any final significance regarding the strength of the crust can be attached to the grouping of residuals discussed under the

[1] F. D. Adams and E. G. Coker, *An Investigation into the Elastic Constants of Rocks, More Especially with Reference to Cubic Compressibility*, 1906, p. 67.

last part of Part II. It leads to a consideration of the relations between mass, distance, and anomaly.

Under the title of "Interpretation of Anomalies in Terms of Masses"[1] Hayford and Bowie show that the excesses and deficiencies of mass to a great distance have an effect upon the gravity anomalies and that therefore the guarded expression "net effective excess (or deficiency) of mass" is necessary for correctness. They give the following tabulation to show the influence of uncompensated masses in the crust in giving gravity anomalies when the gravity is computed on the assumption of isostasy:[2]

TABLE X

Each tabular value is the vertical attraction in dynes produced at a station by a mass equivalent to a stratum 100 ft. thick, of density 2.67, and of the horizontal extent indicated in the left-hand argument, if that mass is uniformly distributed from the level of the station down to the depth indicated in the top argument and from the station in all directions horizontally to the distance indicated in the left-hand argument.

| Radius of Mass | Depth | | | | |
|---|---|---|---|---|---|
| | 1,000 Ft. | 5,000 Ft. | 10,000 Ft. | 15,000 Ft. | 113.7 Km. |
| 1,280 m. (the outer radius of zone E) | 0.0029 | 0.0018 | 0.0011 | 0.0008 | 0.0000 |
| 166.7 km. (the outer radius of zone O) | 0.0037 | 0.0034 | 0.0034 | 0.0034 | 0.0024 |
| 1,190 km. (or 10°40′, the outer radius of zone 10) | 0.0040 | 0.0037 | 0.0037 | 0.0037 | 0.0034 |

On p. 111 it is concluded by these authors that the best working hypothesis is to take

each 0.0030 dyne of anomaly as due to an excess (or deficiency) of mass equivalent to a stratum 100 ft. thick. This working hypothesis is equivalent, as may be seen by inspection of the table just given, either to the assumption that the excess (or deficiency) of mass is uniformly distributed to a depth of 113.7 kilometers and extends to a distance of more than 166.7 kilometers and less than 1,190 kilometers from the station, or that it extends to a distance of 166.7 kilometers from the station and is distributed to an effective mean depth of more than 15,000 feet and less than 113.7 kilometers, or the working hypothesis may be considered to be a combination of these two assumptions.

The mean anomaly of 0.018 dyne, interpreted on this basis of 0.030 dyne being taken as equivalent to 100 ft. of mass, gives a

[1] Hayford and Bowie, p. 108. [2] *Ibid.*, 1912, p. 109.

mean departure from isostatic compensation amounting to 600 ft.; given more exactly by Bowie as 630 ft.

It is seen from the quoted statement that the authors accept, first, as one alternative a very widespread regional net excess (or deficiency) of mass uniformly distributed in depth; or, second, a somewhat broad regional distribution but confined to the outer part of the zone of compensation; or, third, some combination of the two assumptions.

The first assumption would throw a real strain upon the bottom of the zone of compensation and signifies regional compensation to limits very far beyond those stated elsewhere by the authors. It is therefore inconsistent from that standpoint, but gives a smaller vertical load and consequently a smaller vertical departure from the level giving isostatic equilibrium than would a more limited area. If, for example, it be assumed that the radius of the zone limiting regional compensation is 58.8 km., which is about the maximum limit for regional compensation which Hayford allows elsewhere; then it may be computed that for uniform distribution of the excess (or deficiency) of mass to a depth of 114 km., a mass equivalent to 100 ft. of density 2.67 corresponds to an anomaly of but 0.0013 dyne instead of 0.0030. This would, for a mean anomaly of 0.018, signify an average departure over the United States of 1,380 ft. from the level giving isostatic equilibrium, instead of 600 ft.

The second assumption, that the excess (or deficiency) is in the outer part of the crust, gives also a much higher anomaly for a unit mass than would an equally permissible assumption that the excesses or deficiencies occurred at various levels and on the average were at a depth of one-third or one-half of the zone of compensation. The relationship of anomalies to geologic formations, to be discussed later, shows certain variations in density in the outer crust, but the greater parts of the anomalies are not due to this cause. From the previous discussion on the limits of regional compensation it would seem that, on the assumption that the excesses or deficiencies of mass are on the whole uniformly distributed, 0.0024 would be an appropriate figure to use as the mean anomaly for unit thickness of mass. The highest anomalies, however, are

probably better interpreted by 0.0030 as a divisor, since as a class they must be assumed as due to excesses or deficiencies of mass which are both near and large. This does not mean, however, that the larger masses are not assumed as scattered uniformly, according to the laws of chance, through the crust. It is seen, then, that Hayford and Bowie have favored those interpretations which gave a large anomaly per unit mass and have ascribed the total anomaly as on the average to be interpreted on this basis, obtaining thereby a smaller figure as the mean departure in feet from the level for perfect compensation. They have not discussed, furthermore, in the text the influence of deeper-seated variations of density, which might give considerable residuals, nor the possibility that departures from the mean density in opposite directions might balance each other so as to give equal pressures at the bottom of the zone of compensation. The latter case will not seem improbable to the geologist. The great batholiths of the Archean appear to make a universal floor in the crust. They range in composition from granites to gabbros and have come to rest at various levels. Light and heavy masses may well be irregularly distributed in the same vertical cylinder. If at the time of origin the whole were too heavy, a tendency would have arisen for the column to sink until equilibrium was attained. If the whole, on the contrary, were too light, the column would have tended to rise until a heavier base balanced the lighter mass above. Thus, if irregular distribution of density arose as the result of vertical igneous intrusion, the whole region would tend to seek that level where the irregularities would balance.

In order to gain quantitative ideas as to this possibility of partly explaining the anomalies, the writer has made calculations on the following assumptions. A station is situated upon the axis of a vertical cylinder extending from the station to a depth of 114 km. The radius is taken successively at 58.8, 166.7, and 1,190 km. Let such a cylinder be divided into five equal cylinders by horizontal planes. Let each of the five be equivalent in mass to a cylinder of the same radius but only 100 ft. in depth and of density 2.67; in other words, the unit mass as used by Hayford and Bowie. What will be the attraction in dynes per gram pro-

duced at the station by each cylinder respectively?[1] The results are as follows:

TABLE XI

VERTICAL ATTRACTION IN DYNES ON ONE GRAM AT STATION BY CYLINDER 22.8 KM. THICK, DENSITY 0.00357, EQUIVALENT IN MASS TO THICKNESS OF 100 FT. AT DENSITY 2.67

| No. of Cylinder | Depth in Km. from Station to Top of Cylinder | Attraction for Radius of 58.8 Km. | Attraction for Radius of 166.7 Km. | Attraction for Radius of 1190 Km. |
|---|---|---|---|---|
| I | 0.0 | 0.0031 | 0.0032 | 0.0036 |
| II | 22.8 | 0.0017 | 0.0028 | 0.0035 |
| III | 45.6 | 0.0010 | 0.0024 | 0.0035 |
| IV | 68.4 | 0.0007 | 0.0020 | 0.0035 |
| V | 91.2 | 0.0005 | 0.0017 | 0.0034 |

The results for radius 58.8 km. show that masses of this size situated near the bottom of the zone of compensation exert but a fraction of the influence given by equivalent masses near the surface. A balancing of light and heavy masses in a column of this radius would give isostasy at the base and yet produce notable anomalies. For radius 166.7 km. the importance of depth is much diminished. For radius 1,190 km. it practically disappears. This means that a wide regional variation in depth with plus and minus departures from the uniform density, the light and heavy layers balancing, would not produce anomalies provided, as stated, there was isostatic equilibrium at the base.

To give a somewhat extreme illustration; suppose that the upper cylinder, I, is 2 per cent lighter than the mean density of

[1] The formula for making these computations was kindly worked out for me by Professor H. S. Uhler, checking it as given by B. O. Pierce, *Newtonian Potential Function*, p. 8. It is as follows:

$$F = 2\pi\rho\gamma\left[\sqrt{a^2+c^2} - \sqrt{a^2+(c+h)^2} + h\right].$$

in which

$F$ = force in dynes per gram.
$\rho$ = density, in this case = 0.003,57.
$\gamma$ = constant of gravitation = 0.000,000,066,58.
$a$ = radius of cylinder.
$c$ = distance on axis from station to top of cylinder.
$h$ = depth of cylinder; in this case 22.8 km.

For radii of 58.8 and 166.7 km. no correction need be made for curvature of the earth's surface. For $a$ = 1190 km. an empirical correction was obtained by comparing the results with Hayford's computations.

The writer overlooked until later the fact that Hayford and Bowie also give this formula with a different notation on p. 17 of their work.

2.67 and the lower cylinder, V, is 2 per cent heavier. Let these abnormalities be limited areally to the cylinder. This is a departure in density of 0.054, 15.1 times the density 0.00357. The anomalies will be as follows:

TABLE XII

ANOMALIES DUE TO IRREGULAR VERTICAL DISTRIBUTION OF DENSITY

| No. of Cylinder from Table | Density 2 Per Cent from Mean | Anomalies | | |
|---|---|---|---|---|
| | | Radius 58.8 Km. | Radius 166.7 Km. | Radius 1190 Km. |
| I | 2.616 | −0.047 | −0.048 | −0.054 |
| V | 2.724 | +0.008 | +0.026 | +0.051 |
| Resultant anomaly | | −0.039 | −0.022 | −0.003 |

It is seen from this tabulation that, first, irregular superposed but balanced positive and negative distributions of density up to distances as large as the radii of the areas of grouped residuals could produce at least a considerable part of the anomalies; or, second, actual departures from isostatic equilibrium with the resultant strain on the crust could produce them; or, third, a combination of the two. In the second case, as Hayford and Bowie show,[1] the anomalies could result from a layer a few miles thick adjacent to the station and of very abnormal density; or from deep and regional masses of great volume, but departing only slightly from the mean density. The choice between these several alternatives, or the degree to which they co-operate, must be investigated under the following topics.

## RELATIONS OF ANOMALIES TO EXPOSED GEOLOGIC FORMATIONS

The latest data given by Bowie on this subject are shown in Table XIII (p. 222):[2]

These figures of course are not to be regarded as of high precision, as may be seen by comparing the earlier and later results.

[1] *Op. cit.*, Pp. 108–11.

[2] "Some Relations between Gravity Anomalies and the Geologic Formations in the United States," *Am. Jour. Sci.* (4), XXXIII (1912), 237–40.

Hayford and Bowie in their successive publications give the following for the pre-Cambrian and Cenozoic stations, the two groups

TABLE XIII

| Geologic Formation | Number of Stations | Mean with Regard to Sign | Mean without Regard to Sign |
|---|---|---|---|
| Pre-Cambrian | 10 | +0.016 | 0.026 |
| Paleozoic | 31 | −0.003 | 0.019 |
| Mesozoic | 20 | +0.002 | 0.015 |
| Cenozoic | 29 | −0.008 | 0.021 |
| Intrusive and Effusive | 11 | −0.007 | 0.015 |
| Unclassified | 22 | +0.011 | 0.020 |
| All stations | 123 | 0.000 | 0.019 |

to which the attention will be confined. A few stations of high anomaly must have considerable influence on the result, as most of the stations are used in common in all of the estimates.

TABLE XIV

| | Geologic Formation | Number of Stations | Mean with Regard to Sign | Mean without Regard to Sign |
|---|---|---|---|---|
| Hayford and Bowie, U.S.C. and G.S. | Pre-Cambrian | 7 | +0.019 | 0.026 |
| | Cenozoic | 20 | −0.011 | 0.021 |
| Bowie, U.S.C. and G.S. | Pre-Cambrian | 9 | +0.024 | 0.024 |
| | Cenozoic | 33* | −0.007 | 0.021 |
| Bowie, *Am. Jour. Sci.* | Pre-Cambrian | 10 | +0.016 | 0.026 |
| | Cenozoic | 29 | −0.008 | 0.021 |

* Fifteen stations have plus anomalies, 17 have minus anomalies.

Bowie's figures in the *American Journal of Science* will be used in the following discussion.

Bowie favors the explanation that these relations of anomalies to geologic formations are due to slight changes of density extending more or less through the zone of compensation and leading to departures from perfect isostasy. The writer, however, is led to favor the view that about one-half of the contrasted anomaly for these two groups is due to a lesser density within the outer mile of crust beneath the Cenozoic stations, as contrasted to the outer mile of crust beneath the pre-Cambrian stations. The remainder of the anomaly it is thought is explained by the ease of erosion of Cenozoic formations, the resistance to erosion of the pre-Cambrian

rocks. The latter consequently tend to stand above the regional levels. They therefore possess surficial excess both of density and volume.

The average thickness of sedimentary rocks if spread uniformly over the globe is thought to be between 2,000 and 2,500 ft.[1]. Over the pre-Cambrian areas it must average much less; over the areas of later formations much more. Under the Cenozoic stations assume:

| | |
|---|---|
| 1,000 ft. of sediments at density | 2.40 to 2.50 |
| 4,000 ft. of sediments at density | 2.50 to 2.60 |
| Giving a total of 5,000 ft. at density | 2.48 to 2.58 |
| With a deficiency of density of | 0.19 to 0.09 |

Under the pre-Cambrian stations assume:

| | |
|---|---|
| 5,000 ft. of crystalline rock at density | 2.75 to 2.80 |
| An excess of density of | 0.08 to 0.13 |

This does not involve the improbable assumption that below the outer 5,000 feet of crystalline rock of density 2.75 to 2.80 the density suddenly decreases to 2.67 and then remains constant throughout the zone of compensation. The vertical density gradient, *if uniform for all points*, has but little effect, it being the *horizontal* variations of density which enter into the problem of isostasy. To maintain conformity with Hayford's figures, therefore, the density 2.67 will be frequently assumed as the mean density of the lithosphere, although the previous discussion shows that it cannot be assumed as the density of the outer mile of crystalline rocks when comparing these to the mile of sedimentary rocks taken as the mean depth underlying the Cenozoic stations.

In comparison with this thickness of 5,000 ft. the average area of formations is very great. A plane sheet of rock 100 ft. thick and of density 2.67, if of indefinite extent, will produce an anomaly of 0.0034 dyne upon a point outside of it, irrespective of the distance to that point. This theory may be applied without gross error to the relation of surface geologic formations to anomalies. If this unit mass be expanded from 100 to 5,000 ft. thickness, the

[1] F. W. Clark, "Data of Geochemistry," *Bull. 491, U.S. Geol. Surv.*, 1911, p. 30.

density will be decreased to 0.053 that of water. The data may then be tabulated as follows:

TABLE XV

COMPUTED ANOMALIES DUE TO DENSITIES OF SURFACE FORMATIONS

| | Deficiencies or Excesses of Density | Anomalies in Dynes per Gram Due to Thickness of 5,000 Ft. |
|---|---|---|
| Unit mass | 0.053 | 0.0034 |
| Cenozoic | −0.19 | −0.012 |
| | −0.09 | −0.006 |
| Pre-Cambrian | +0.08 | +0.005 |
| | +0.13 | +0.008 |

These mean anomalies of the pre-Cambrian due to the greater density of the outer 5,000 ft. of rock, when compared to the Cenozoic anomalies, are, as shown by this tabulation, at a minimum 0.011 greater, at a maximum 0.020 greater, at a mean 0.0155 greater. The difference of the means shown by geodetic measurement was 0.024. The specific gravities seem to have been taken as far apart in limits as is allowable and the assumed mean thickness of sediments as 5,000 ft. beneath the Cenozoic stations is a generous figure; the mean thickness is more likely to be less, rather than greater. The means for the geodetic anomalies as related to geologic formations are perhaps subject to about the same degree of error as the determinations of the anomalies from the specific gravities and thickness. The result, although not of a high order of accuracy, shows that although the range in specific gravities accounts for a considerable part, perhaps one-half or two-thirds, of the relation of anomalies to geologic formations, it can hardly account for the whole.

To find the cause for the remaining portion of the anomaly, two hypotheses may be considered: first, that it is due to a slight regional excess of density extending to a depth of 114 km., the hypothesis favored by Bowie; or, second, that the Archean areas on the average stand higher than the Cenozoic by virtue of resistance to erosion.

The geologic evidence as it is at present understood is against the first hypothesis and in favor of the second. This statement

is based on the view that Archean and Proterozoic areas have tended to be rising elements of the continent. Erosion instead of sedimentation has been dominant in later geologic time, which is the reason why these rocks are now exposed as surface formations. If there is any deep-seated departure of density from the mean this tendency to rise should correspond, however, to a deficiency of density persisting through the geologic ages, extending through much of the zone of compensation and offsetting the more than average surface density. Such a regional deficiency is opposite in character to the excess which is postulated by Bowie as an explanation of the positive anomalies.

Assume then as the next step in the argument that the density of the zone of compensation beneath the pre-Cambrian areas to a depth of 114 km. is the same as under Cenozoic areas except for the outer 5,000 ft., both having a mean density of 2.75 to 2.80, but taken here as 2.67. The outstanding anomaly in that case is due to a longer mean column for the pre-Cambrian areas and consequently greater mass above the level of complete compensation. If the mean radius of these longer pre-Cambrian and shorter Cenozoic columns is as great as 166.7 km., then the unit excess or deficiency of mass of 100 ft. at density 2.67 when spread over these columns will correspond to an anomaly of 0.0024. If the mean effective areas of the pre-Cambrian and Cenozoic formations affecting individual stations are less, the unit mass will give a smaller unit anomaly. If the mean effective areas are greater, the unit anomaly will not, however, rise above 0.0035. Assume then in conclusion a mean radius of 166.7 km., an anomaly of 0.0024 dyne as resulting from 100 ft. of added mass of mean density, and the outstanding anomaly not accounted for by the surficial densities but due to an outstanding difference in volume as between 0.008 and 0.012. These figures correspond to a differential mean elevation of 330 to 500 feet of the pre-Cambrian above the Cenozoic, due to erosion. To physiographers such a conclusion will seem quite in accord with the geologic evidence testifying to the resistance of pre-Cambrian formations.

The character of the Archean and Proterozoic anomalies enters into the problem of crustal rigidity in the following way. If there

were local and close compensation, then as erosion removed the softer surrounding rocks there should be isostatic upwarping of such areas of denudation and relative downwarping of the uneroded crystalline areas. Such warping of the Mohawk, St. Lawrence, and Champlain valleys with respect to the Adirondacks has not been noted, though the problem from the standpoint of field evidence has not been fully studied. The physiographic evidence that residual mountain masses known as monadnocks or unakas have not been shown, however, to be marked by local downwarping and, on the contrary, certainly stand in relief due to circumdenudation, combines with the geodetic evidence of the average excess of gravity for the resistant areas of pre-Cambrian formations, to suggest effective rigidity against the stresses produced by erosion. The evidence, however, as developed thus far from the geodetic standpoint shows that there are more important factors than that of the surface geologic formation, since the larger anomalies are much greater than these figures which have been discussed and hold but little relation to either relief or surface geology. In fact Hayford and Bowie do not find any discoverable relation between the anomalies in general and the topography.

It is thought by the writer, however, that if stations were located especially to test the intensity of gravity over various broad plateaus remaining by circumdenudation and the intensity compared with that over adjacent broad areas of lower level, the mean differential anomalies due to the surface excess of mass in the plateau over the lowlands would rise to a larger figure than the 0.008 to 0.012 dyne which has remained to be explained in the present discussion. These figures are low because certain pre-Cambrian areas, like those in the vicinity of Baltimore and Washington, have been lowered by prolonged denudation and do not stand markedly above the level of younger formations. Furthermore, the tendency of broad pre-Cambrian areas to stand above sea-level is very probably of an isostatic nature. This implies under such areas a slightly lower mean density to the whole zone of compensation which would diminish the anomaly due to the surface elevation. In individual areas of 100 to 200 km. radius, however, such a relation of positive anomaly to pre-Cambrian

formations and plateaus of circumdenudation may not be found, since it is clear that the anomaly from this cause may be much more than neutralized by other causes. A large number of stations covering broad areas would therefore be required adequately to eliminate these other influences from the means.

### LARGE OUTSTANDING ANOMALIES NOT RELATED TO GEOLOGY OR TOPOGRAPHY

In Fig. 5, of Part II, the anomalies are shown for all stations in the United States. It is seen that they possess an areal gradation in magnitude which permits the drawing of anomaly contours. The excessive anomalies of both signs cover oval areas in various parts of the country and show a common disregard of physiographic provinces, structural provinces, and geologic formations. Looking at Fig. 5, one cannot see in either the distribution of anomalies or trends of contours a reflection of Atlantic Coastal Plain, or Appalachian Mountains, or Mississippi Valley.

Typical examples of the lack of necessary relation of the large anomalies to geologic formations are seen in the following tabulation:

TABLE XVI

| No. | Station | Geologic Formation | Anomaly |
|---|---|---|---|
| 123 | Albany, N.Y. | Cambro-Ordovician | −0.043 |
| 74 | St. Paul, Minn. | Cambro-Ordovician | +0.059 |
| 96 | Mena, Ark. | Pennsylvanian | −0.052 |
| 101 | Helenwood, Tenn. | Pennsylvanian | +0.040 |
| 53, 56 | Seattle, Wash. | Quaternary | −0.093 |
| 112 | Olympia, Wash. | Quaternary | +0.033 |

The lack of relation of these anomalies to topography is equally striking. It is clear then that internal conditions in the crust, not expressed on its surface, must be the principal cause of these larger departures from isostasy. The large anomalies show their relationship to internal causes most clearly, but the smaller anomalies may also by analogy be ascribed in part to such hidden causes. The results, however, of surface activities—circumdenudation, sedimentation, tangential pressure, or extravasation—must show in large ratio over regions where the internal variations from uniform density are small; but over the greater part of the United States

the distribution of anomalies appears to depend more upon the internal than upon the external departures from regional uniformity and complete isostasy. The internal heterogeneities of mass are therefore presumably greater than the shiftings of mass due to external activities.

### CRITERIA FOR SEPARATING VERTICALLY IRREGULAR COMPENSATION FROM REGIONALLY INCOMPLETE COMPENSATION

Suppose the topography smoothed out to a mean level over areas as large as the limits for regional isostasy. The deflection residuals and gravity anomalies would then be due to one or more of three internal causes; first, vertically irregular or laterally displaced compensation; second, regionally incomplete compensation above the bottom of the zone of compensation because of the effective rigidity of the crust above that level; third, regionally incomplete compensation above a certain level because the zone of compensation may be deeper in places, transferring stresses into a deeper rigid earth. The existence of a general approach toward compensation and away from absolute rigidity suggests that the last is not so important as the first two causes. Under this section then will be considered these two causes, their effects upon the deflections of the vertical and the intensity of gravity, with the purpose of drawing criteria by which the action of the two causes may be recognized and separated. To do this it will be necessary to discuss here to some extent the theory of the attraction of underground masses upon stations at the surface of the earth. It has been shown that balanced irregularities in the vertical distribution of densities through the zone of compensation could give pronounced anomalies without disturbing the isostatic equilibrium at the bottom of the zone, since the total weight of the column could still be normal. To show the effect of such balanced irregularities upon a point outside of the column:

Take a vertical line and a horizontal line which intersect. The masses whose effects are to be investigated will be distributed on the vertical line. The effects are to be determined for points on the horizontal line. To express the trigonometric relations between any point on the vertical and any point on the horizontal line, let a point on the vertical line at depth $D$ be defined as at a vertical

angle $\theta$ below a point on the horizontal line; the latter to be defined as at distance $R$ from the intersection.

Let the gravitative attraction of unit masses along this vertical line upon any other point either in or outside of this line be represented by $F$. The horizontal component will be the force producing deflection of the vertical and may be represented by $Fh$. The vertical component will give the acceleration of gravity due to the unit mass and may be represented by $Fv$. Taking the unit mass such that the constants will have a value of unity, the following relations are deduced:

Attraction of unit mass at depth $D$, upon a point at $R$:

$$Fh = \frac{\cos^3 \theta}{R^2}$$

$$Fv = \frac{\tan \theta \cos^3 \theta}{R^2}$$

For the intersection point,

$$R \text{ and } \theta = O \text{ and}$$

$$Fh = 0$$

$$Fv = \frac{1}{D^2}$$

Let the depth of the zone of compensation, 114 km., be taken as unit distance, 1.00, and for purposes of discussion let points I, II, III, IV be located on a vertical line at depth of 0.25, 0.50, 0.75, and 1.00 as shown on Fig. 6. Solving the equations for these points and for various values of $R$ gives the following tabulation:

TABLE XVII

TABLE OF RELATIVE ATTRACTIONS

(Not in dynes per gram)

| ATTRACTION BY UNIT MASSES AT | | | ATTRACTION AT STATIONS FOR VARIOUS VALUES OF $R$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Depth | Angle below $R=1.00$ | $R=0$ | | $R=0.25$ | | $R=0.50$ | | $R=1.00$ | | $R=2.00$ | |
| | | | $Fh$ | $Fv$ | $Fh$ | $Fv$ | $Fh$ | $Fv$ | $Fh$ | $Fv$ | $Fh$ | $Fv$ |
| 0..... | 0 | 0 | 0 | 0 | 16.00 | 0 | 4.00 | 0 | 1.00 | 0 | 0.25 | 0 |
| I..... | 0.25 | 14°02′ | 0 | 16.00 | 5.60 | 5.60 | 2.88 | 1.44 | 0.91 | 0.23 | 0.24 | 0.03 |
| II..... | 0.50 | 26°34′ | 0 | 4.00 | 1.44 | 2.88 | 1.40 | 1.40 | 0.72 | 0.36 | 0.23 | 0.06 |
| III..... | 0.75 | 36°52′ | 0 | 1.78 | 0.51 | 1.52 | 0.68 | 1.04 | 0.51 | 0.38 | 0.21 | 0.08 |
| IV..... | 1.00 | 45°00′ | 0 | 1.00 | 0.21 | 0.91 | 0.36 | 0.72 | 0.35 | 0.35 | 0.18 | 0.09 |

Fig. 6 shows the curves for $R=1$. For any other value of $R$ the curves would be the same in form, but the scales of ordinates and abscissas would be changed. These curves may be used therefore in a general way.

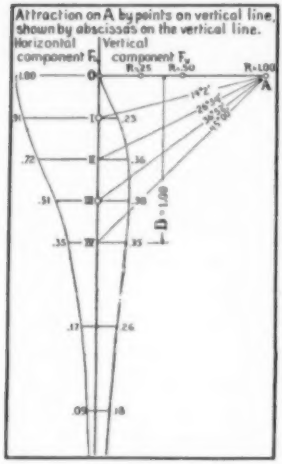


FIG. 6

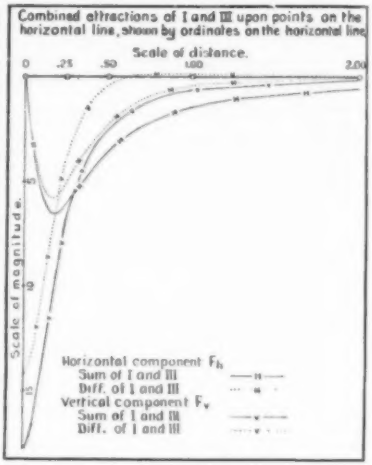
Combined attractions of I and III upon points on the horizontal line, shown by ordinates on the horizontal line.
Scale of distance.
0
.25
.50
1.00
2.00
Scale of magnitude.
Horizontal component $F_h$
Sum of I and III
Diff. of I and III
Vertical component $F_v$
Sum of I and III
Diff. of I and III

FIG. 7

FIG. 6.—Curves showing relative attraction of all points on the vertical line upon a point at distance $R=1$.

FIG. 7.—Combined attractions upon all points on the surface by unit masses of like and unlike signs at I and III of Fig. 6.

The table shows that if unit masses at II and III have the same sign the *horizontal component, Fh,* for the *sum* of their attractions at $0.25R$ will be 1.95, at $R$ it will be 1.23, which is 63 per cent of the value at $0.25R$. If the unit masses have unlike signs the *horizontal component of their difference* at $0.25R$ will be 0.93, at $R$ it will be 0.21, which is but 23 per cent of the value at $0.25R$. The *vertical component, Fv,* due to the *sum* of the masses at $0.25R$ is 4.40; at $R$ is 0.74. The *vertical component* due to the *difference* at $0.25R$ is 1.35; at $R$ is 0.02 and of opposite sign. It is noticed that the gravity anomaly diminishes rapidly with increasing horizontal distance from these two masses and passes through zero. The deflection of the vertical first increases sharply and

then diminishes, but less rapidly than the gravity anomaly. It is important to notice that in both cases the total influence due to masses of *opposite* sign diminishes much more rapidly, and where their distance apart is 0.25 their influence is small at distance $R$ and negligible at $2R$. This gives a means of determining whether, in the crust, anomalies and deflections are due to regional departures from isostasy or to balanced irregularities in density without absence of isostasy at the base of the zone.

To give a further illustration of balanced departures in density spread over a greater vertical distance, and representing in that way perhaps a more average case, assume that an excess or deficiency equivalent to a unit mass is at depth 0.25 and another at depth 0.75. The following tabulation shows their influence upon the surface of the earth at increasing horizontal distances.

TABLE XVIII

ATTRACTION BY UNIT MASSES AT I AND III UPON POINTS ON THE HORIZONTAL LINE

| Component | Position and Sign of Mass | Horizontal Distance on Surface of Earth from Vertical Line | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 0.25 | 0.50 | 1.00 | 2.00 | 4.00 |
| *Fk*..... | − I −III | 0 | −6.11 | −3.56 | −1.42 | −0.55 | −0.121 |
| | − I +III | 0 | −5.09 | −2.20 | −0.40 | −0.03 | −0.003 |
| *Fr*..... | − I −III | −17.78 | −7.12 | −2.48 | −0.61 | −0.11 | −0.015 |
| | − I +III | −14.22 | −4.08 | −0.40 | +0.15 | +0.05 | +0.007 |

The data in this table are represented by the curves of Fig. 7. It shows that for this arrangement of masses the influence on the surface falls off rapidly at a horizontal distance between 0.25 and 0.75, which are also the vertical depths to I and III. When the masses are of opposite sign the anomaly passes through zero at a horizontal distance of about 0.6, and the deflection force for opposite sign decreases to half the value of the sum at about 0.75. The ratio between the effects of like and unlike masses becomes more marked the greater the distance of the point, although the actual magnitudes of the forces decrease.

Now assume the unit masses at I and III to be parts of masses of like density extending to the left of o to a distance $N$. Consider the aggregate effect upon a given point, as that at o.50, or in general at point $R$. The effect of each unit at distance $x$ to the left of o upon the point at o.50 will be measured by an ordinate at a distance $x$ to the right of o.50. This will give the same aggregate result as concentrating the masses at o and summing up the area of the curve to the right of the point at o.50 to a distance of o.50+ $N$. Stated in general terms, masses at depths I and III extending linearly to distance $N$ to the left of o will have an aggregate effect upon a point $R$ equal to the area of the curve between $R$ and $R+N$.

As to the aggregate effect on $Fv$, the gravity anomaly: If the two sheets are of negative density, it is seen that the result will be an increased negative anomaly over the effect of the separate unit masses. If the lower mass is, however, of positive density, the result for ordinarily limited sheets will be a change between o and o.50 from a large negative to a small positive anomaly. This may be compared with the effects of other possible distributions of mass upon the gravity anomaly.

If the anomaly due to the *adjacent* departure from uniform distribution is of the mean value or greater, the *more distant* abnormal masses will have but relatively small influence. This is because the higher anomalies, with the exception of Seattle, are but two or three times the mean. Further, in a zone of large radius there are a greater number of positive and negative departures. Their aggregate effect, according to the laws of chance distribution would increase but slowly and this effect is diminished by distance according to the formula $\frac{Fv = \tan\theta \cos^3\theta}{R^2}$.

A reversal from a large anomaly of one sign to a *large* anomaly of opposite sign, rather than a *small* one of opposite sign, marks then in general a passage from an area of excess or deficiency of mass to the opposite. A gradual change in the anomaly is the reflection of a change in the subsurface abnormalities nearly as gradual. If the areal variations show that the passages of the anomaly through zero are not frequent, they go to show that limited notable irregularities of density of opposite sign in the

same column are rare. Furthermore, it has been shown under the topic "The Variable Rate of Compensation upon Gravity Anomalies" that a variable distribution of balanced densities has more effect if in areas of between 100 and 200 km. radius and has but little effect on anomalies if the balanced densities extend over much larger areas.

As to the aggregate effects produced upon *Fh*, giving deflection residuals, by these sheets I and III: If the sheets have like sign the deflection force, as shown in Fig. 7, will die out somewhat gradually and extend to considerable distances. If they have unlike sign the deflection force will fall off sharply between 0.25 and 1.00. If, however, the abnormalities of density should disappear gradually, that is, if the sheets did not terminate sharply at 0, this rate of falling off would be slower. Reversals of sign of the *deflection residuals* would require areal, not vertical, irregularities of mass. They could not take place as an effect of distance from a single mass or of two masses of unlike sign and vertically over each other. Where sharp reversals of sign take place in the deflection residuals the presence of areally contiguous areas of unlike departures in mass is shown. A mere difference in magnitude of excess of mass but of the same sign may, however, produce changes in the sign of the deflection residuals. In the irregular areal distribution of abnormal masses not balanced by being over each other, the deflection areas of like sign would thus tend to be smaller than the anomaly areas of like sign. A gradual fading-out of the deflection residuals would be the mark of gradual fading-out of the abnormal mass or the increasing influence of distant masses.

Various special combinations of three or more masses could at any one point simulate the relations indicated, but such special relations would not be of common occurrence and could not give a generality of relation of this sort.

There have thus been drawn up a set of criteria by which balanced irregularities within the zone of compensation may be distinguished from regional departures from isostasy. It remains to apply those to the areal distribution of gravity anomalies and deflection residuals as given by Hayford and Bowie. It must be recognized, however, that the stations, although numerous as

compared to previous measurements, are yet very scattered for the precise application of these tests and can at best give but qualitative results. It is thought, nevertheless, that the general nature of the answer is determinative.

## GRAVITY ANOMALIES CAUSED LARGELY BY REGIONAL DEPARTURES FROM ISOSTASY

The first question is: To what degree do the areas of excess (or deficiency) of mass as indicated by gravity anomalies coincide with areas of excess (or deficiency) as shown by the deflection residuals? In Fig. 5[1] there are indicated a number of ovals shown in dot-and-dash outline and marked + or −. These are the definitely bounded areas of excess or deficiency of mass indicated by the deflection residuals. The entire surface of the crust must be constituted of such areas, but only a few are surrounded by sufficient observations to permit a boundary to be drawn at present. Even this boundary must not be regarded as sharply definite. Beside these ovals there are shown in illustrations 5 and 6, Hayford, 1909, areas of residuals characterized by like sign, referred to in the present paper as "areas of grouped residuals." They are not definitely bounded on all sides and are not shown in Fig. 5 of this article. The areas of grouped residuals show the intercepts across areas of like sign, but at least two intercepts at an angle to each other are necessary to define well the limits of the area of which they are a part. As the deflection stations are situated largely in lines or zones across the country and not surrounding the areas of like sign, it is seen why the boundaries of relatively few areas are well determined. In so far, however, as the relations of the areas of positive and negative anomaly to positive and negative deflections of the vertical are apparent, Hayford and Bowie state: "The gravity anomalies corroborate the evidence given by the deflections. In no important case are the anomalies and deflections contradictory."[2]

It is seen by inspection of the illustrations by Hayford, and also by the discussion in Part II of this article, that the areas of

[1] P. 153, Part II.

[2] Hayford and Bowie, 1912, p. 112.

like sign of deflection residuals are more sharply bounded and smaller in size than the areas of like sign of gravity anomalies. The latter occur commonly in areas so broad that a vertically balanced irregularity in the distribution of density would have but little effect. Yet the large gravity anomalies occur in the midst of such large areas, as shown on Fig. 5. There are, furthermore, few sharp reversals of sign of the gravity anomalies save those at different elevations in mountainous regions and these are explained by the presence of regional compensation. There are, on the contrary, many sharp reversals of the deflection residuals.

It is to be concluded, therefore, that, although some degree of balancing of irregularities in the same column no doubt exists, this is not a common or controlling explanation of the anomalies and residuals. They are overshadowed by a distribution which points, on the contrary, to regional departures from isostasy by regional excesses or defects in density.

In the location of stations, the deflection observations are arranged at relatively close intervals and in linear zones, owing to the necessity of triangulation. They give the most information as to the size of areas of relative excess and defect. But two areas of relative excess and defect may both be in absolute excess or absolute defect. The gravity stations are more widely scattered. The local variations are in consequence poorly defined, but the limits of absolute excess and defect of mass are determined with more accuracy. They appear to show that areas as large as 1,000 by 2,000 km., 620 by 1,240 miles, may depart in one direction from isostasy, but only to a moderate amount. It is seen from Fig. 5 that between Florida and a line drawn from Lake Superior to the Rio Grande the broad areas of less than mean anomaly are negative. From this line a great positive area extends to the northwest. The quarter of the United States bordering the Pacific Ocean is, however, another great region of negative anomalies. Upon these broad regions of mean anomaly or less are superposed smaller and better-defined areas of more than mean anomaly, negative and positive areas occurring in the same broad region. These smaller areas are inclosed by the 0.020 anomaly contour. They commonly range from 300 to 400 km. across, 200 to 250 miles, but the maxima

which reach above 0.040 are much smaller. The limits of regional isostasy appear then to vary with the amount of the load. Well-defined areas 200 to 250 miles in breadth may stand vertically 800 to 1,600 feet on the average from the level, giving isostatic equilibrium, and their central portions reach still higher values. They represent the limits of regional isostasy discussed in an earlier part. But these are superposed on broader areas which may extend for a thousand miles or more and lie as much as 400 to 800 feet either above or below the level for equilibrium. Stresses given by loads of this order are then not restricted in area to the limits set for higher values.

The size of the areas of intenser stress reveal the capacity to which the earth can carry mountain ranges uncompensated by isostasy. The size of the areas of weaker stress shows the capacity of a considerable portion of a continent to lie quiescent while the surface agencies carry forward their leveling work. This is the present state of this particular continent after a geologic period of world-wide notable vertical movement and adjustment. It is not likely, therefore, that these loads measure the maximum stress-carrying capacity of the earth. They may be more in the nature of residual stresses which the earth can hold through periods of discharge of stress. East of the Cordillera there has been but little local differential movement and these areas have lain in crustal quiet for long geologic ages, being subject only to broad and uniform crustal warping of moderate amount. It is to be presumed, therefore, that the strains which exist in such regions by virtue of the regional departures from isostasy are of ancient date and well within the limits of crustal strength.

It would seem probable for such conditions, from the standpoint of mechanics, that the zone of compensation is not sharply limited, with its implication of marked lowering of rigidity at its base; nor the distribution of compensation uniform to the base. It seems more probable that the abnormalities of density and the resultant strains should fade out through a considerable depth more after the manner suggested by Chamberlin.

[*To be continued*]

# ON THE NAMES OF AMERICAN FUSULINAS[1]

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Though material both good and abundant is not lacking, our American Fusulinas have never been carefully studied by any American investigator and it has remained for an alien to give us a comprehensive treatment of them. This is done in Schellwien's monograph of the Fusulinidae which since his untimely death has been carried on by other hands, the North American portion by Hans von Staff[2] having recently been published. Of the scientific part of this paper it will suffice to say that it appears to represent much research, yet one cannot but fear that the lack of judgment shown in the proceedings of nomenclature has extended to the scientific portion also.[3] It is to certain points of nomenclature that attention is here directed.

In order not to shock the sensitive reader too violently I will begin with a minor point. Our common Pennsylvanian species of Fusulina was described by Say as *Miliolites secalicus*, the generic reference being later changed to Fusulina. In the monograph by von Staff this is arbitrarily shortened to *Fusulina secalis*. Say's word *secalicus* was clearly derived from the Latin "*secale, is*," a kind of grain, and while a more appropriate termination might have been chosen in forming the adjective from the noun, *secalicus* is a gem of pure latinity compared with many words in the shady lexicon of paleontology. Von Staff's term *secalis* can be nothing

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] *Paleontographica*, Band 59, 4te Lieferung, 1912, pp. 157 ff.

[3] One rarely meets nowadays with a work whose presentation is as poor as this. The text is without plate references and the plates without page references. The distribution of the species is given only incidentally, and apparently is not given completely or in detail. The magnification of the figures is not stated either on the plates themselves or on the plate descriptions. I think it is given somewhere in the text but on my last reference to the work, I did not have time to read it through completely, and so am unable to say definitely that the fact is or is not stated.

but the genitive case of the same noun, *secale*, and is even less appropriate than the adjective, besides which there is very little precedent, in paleontologic literature at all events, for making the species name a common noun in the genitive, although proper nouns in the genitive are not rare. It seems clear that the only acceptable form of this name is *secalica*.

The second point which I propose to raise concerns the status of *Fusulina secalica* Say, *Fusulina centralis* Say, and *Fusulina elongata* Shumard of which the first two are retained as valid species in von Staff's monograph, and the last cited as *Fusulina extensa* var. *californica*, *F. extensa* being a manuscript name of Schellwien's and *californica* a new varietal designation. To be more explicit, Shumard's original description of *Fusulina elongata* is listed as a doubtful synonym and my later citation, in 1908, as an undoubted synonym of the manuscript species and new variety. Von Staff points out the indubitable fact that Shumard's description is very meager, so that the only important feature of *F. elongata* given is the great length, in which respect the later specimens described and figured by me are distinctly, though perhaps not greatly, inferior to Shumard's measurement. For this reason Shumard's work is cited with doubt and mine without doubt in the synonymy. Von Staff's treatment of these three species is inconsistent, for if the description of *F. elongata* is meager it is less meager than that of *F. centralis*, and if the description of *F. elongata* assigns a greater length than has actually been found in later collections, that of *F. secalica* assigns a feature which is quite alien to the whole genus Fusulina, a solid axis.

In fact, all three species are too poorly described to be determinable, and since the typical collections are now lost, it is necessary to redefine them in the light of new studies based on other material. The method employed in the case of *F. secalica*[1] and *F. elongata*[2] was to base the later studies on material from about the same locality and horizon as the original, and in this the possibilities of satisfactory results depend largely upon whether one or several species are there present. If more than one are present

[1] *Am. Jour. Sci.* XVII (1904), 234.

[2] *U.S. Geological Survey, Professional Paper 58*, 1908, p. 62.

the statements of the author are liable to afford but inadequate means for determining which was the authentic species.

Very large, very elongated Fusulinas are found in inconceivable multitudes in the Guadalupe Mountains. It is possible that specimens occur which are one-fourth larger than the largest seen by me, but it does not follow that they necessarily belong to a different species. Even if there is a larger form which is a distinct species, it is, humanly speaking, impossible that Shumard could have obtained specimens from this region without much the greater portion of them belonging to the smaller type. It is also, humanly speaking, absolutely certain that even if he had any of the larger shells at all, the smaller ones were included along with them as *F. elongata*. By implication I restricted the name *F. elongata* to the smaller form, if, indeed, there is any specific difference. By implication von Staff would restrict *F. elongata* to the larger form whose existence is hypothetical. Which restriction has priority, if either is valid at all, is a matter of record. Which is the more conservative and reasonable needs no argument. I have really no doubt that the form which I figured in 1908 is the true *F. elongata* of Shumard, while the status of *F. secalica* is much less certain and *F. centralis* has almost no standing at all. Consequently, *F. elongata* is the proper name for the species; the "new variety" *californica* is a straight synonym; and the European or Asiatic form for which Schellwien intended to use the name *extensa* will be a new variety or species as is subsequently determined.

Furthermore, von Staff has "emended"[1] *F. secalica* so as to make it include a different species from that identified by me and also probably a different species from that originally described by Say. As to the first statement there can be little doubt, since von Staff's *F. secalica* is a much more inflated form with much more strongly folded septal walls, and since von Staff himself identifies my *Triticites secalicus* with his *F. centralis* Say.[2] (Nevertheless, in 1912 he placed my citation in the synonymy of *F. secalica*.)

My *Fusulina* (*Triticites*) *secalica* agrees very closely with Say's description, so that von Staff's *F. secalica* differs from Say's *Fusulina* (*Miliolites*) *secalica* in the same particulars in which it differs from

[1] *Neues Jahrbuch*, Beilageband XXVII (1909), 494 ff.

[2] *Op. cit.*, 1909, p. 508, description of Fig. 9, Pl. 8.

my *F. secalica*, namely, it is more inflated and has the septal walls more strongly folded. In evidence of this statement Say gives the length of his typical *F. secalica* as 0.3 inch and the breadth as $\frac{1}{12}$ inch, so that the ratio is 3.6:1, whereas von Staff gives the ratio in his form as 2.5:1 or 2:1, with a ratio of 3.2:1 and 1.6:1 in extreme forms only (*op. cit.*, p. 496). As to the folding of the septal walls, Say describes the shell as composed of tubes or siphons placed parallel to one another, a phraseology indicating, I should think, chambers uninterrupted by foldings of the inclosing walls. However, Say probably did not study the form by means of sections, and may have based his statement partly on the appearance of the external suture which is always straight, no matter how much the septal walls are folded within the shell.

Dr. J. W. Beede[1] was the first one to revive Say's *F. secalica* and give figures of it. He figures numerous specimens in side view and also one in thin section (axial). He does not, however, state whether the figures are enlargements, nor does he give the localities from which the originals were obtained. The figure representing the thin section is clearly an enlargement, and I suspect that some of the others are also. The largest has an axial length of 18 mm., much greater than that of any Fusulina which I have seen from Kansas. The proportions vary considerably in these figures, but with few exceptions they range between 3.6:1 and 3.2:1. This then is a more slender shell than von Staff's *F. secalica*, and if the figures are of natural size, a larger. It has much the same proportions as my *F. secalica* and as Say's original *F. secalica*, but it may be much larger.

The figure showing a thin section is considerably less slender than the others, and has more the shape of von Staff's *F. secalica*. Its proportions are almost exactly as 2:1. From this fact and from the bluntness of the ends (the other figures are terminally somewhat attenuated) I infer that this section does not exactly follow the axis but is somewhat oblique to it, though passing through the initial cell. The septal walls are much simpler than in von Staff's *F. secalica* (cf. Fig. 3, Pl. 15, of his 1912 publication), but, on the other hand, they are represented as porous, a feature apparently characteristic of the latter.

[1] *University Geological Survey of Kansas*, Report, Vol. VI (1900), p. 10.

It is doubtful whether Dr. Beede's *F. secalica* is the same as Say's *F. secalica;* doubtful also whether it is the same as von Staff's, since it is much more slender, possibly larger, and with much less strongly plicated walls, at least as represented in the figure.

My *Triticites* or *Fusulina secalica* came from about the same locality and horizon as the original and agrees with the original description in all the characters mentioned, though this agreement unfortunately is not adequate to establish complete specific identity.

Everyone probably would admit that we do not actually know what true *F. secalica* is, but it might well be argued that the species had been re-established by emendation in the reports of Dr. Beede, or of myself. Dr. Beede's emendation has priority over mine, but mine I believe is more probably the original *F. secalica* of Say. My species is clearly, and Dr. Beede's may well be, distinct from von Staff's. I should not object to seeing Dr. Beede's interpretation or any other supersede my own if it were shown to be the authentic species or more probably the authentic species, but the facts are, if anything, just the opposite, and it would be especially inadvisable to adopt Dr. Beede's interpretation if it entailed the inclusion (as it probably would) of von Staff's also, since his is in all probability distinct from the original.

Until some better evidence comes to light, therefore, it would seem to be necessary to interpret *F. secalica* on the basis of my *Triticites secalicus* of 1904. Von Staff is probably correct in identifying the latter with his *F. centralis*, but as his application of this name is entirely arbitrary, *F. centralis* von Staff must for the present be written in the synonymy of *F. secalica* Say.

On the other hand, *F. secalica* von Staff almost certainly goes out of the synonymy of *F. secalica* Say, together with all the American citations of *F. cylindrica* which agree with it, including possibly *F. secalica* Beede.

The proper name for this species (*F. secalica* von Staff *non* Say) I am unable to suggest. It may be undescribed, but I suspect that it is the authentic *F. ventricosa* (*F. cylindrica* var. *ventricosa*) of Meek and Hayden, and that von Staff's *Girtyina ventricosa* is a still different type. *F. cylindrica* var. *ventricosa* was described (without figures) from Juniata and Manhattan, Kansas, but Meek and Worthen later identified and figured it from a lower horizon

(probably) in Illinois. It is the latter form which von Staff cites as *Girtyina ventricosa*, without recognizing the fact that the original variety *ventricosa* was a much larger and less ventricose[1] form and not improbably a different species. This inference, based on intrinsic characters, is verified by the fact that von Staff recognizes *G. ventricosa* only from Illinois, although having a full series of Kansas specimens in his hands for identification. *G. ventricosa* von Staff, therefore, is almost certainly a distinct species from *F. cylindrica* var. *ventricosa* Meek and Hayden, which is, on the other hand, possibly the same as von Staff's *F. secalica*.

The gentle author has considerable to say about my proposed genus Triticites, of which he disapproves in emphatic language and liberal exclamation points, some of which might have been saved if he had fully understood the statements which he was criticizing. The studies of special investigators have, indeed, minimized the differences on which Triticites was separated from Fusulina, but it was regrettably heedless for von Staff, after condemning Triticites, to turn around and propose the new subgenus Schellwienia and at the same time to include in Schellwienia the type species of Triticites, *T. secalicus*. If a new name is needed for the group in question Triticites clearly should be employed.

Even if, however, one adopts the classification proposed by von Staff, which I think few will do, a new name is not needed here. He proposes to include both Fusulina and Schwagerina as subgenera in a single group which he regards as forming one genus and for which he retains the name Fusulina. It is for Fusulina in the old and strict sense that Schellwienia is introduced. This seems to me comparable to Hyatt's course in using Goniatites as a general term and introducing Glyphioceras for Goniatites ss., and it is equally inadmissible. If the author regards Schwagerina as a subgenus of Fusulina, the proper course is to retain Fusulina ss. as the name for the companion group. From the present evidence Schellwienia is a synonym of Triticites, and Triticites of Fusulina ss., a name which must be retained in a subgeneric sense even if von Staff's classification is adopted.

[1] Meek gives the length as $\frac{1}{2}$ inch (13 mm.) and the diameter as $\frac{3}{10}$ inch. This makes the ratio of course 2.5:1. *Girtyina ventricosa* is described as having an axial length of at most 5 mm. and the ratio as 1.7:1.

# THE RED BEDS BETWEEN WICHITA FALLS, TEXAS, AND LAS VEGAS, NEW MEXICO, IN RELATION TO THEIR VERTEBRATE FAUNA

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During the summer of 1912 the author traveled by wagon from the north line of Oklahoma, south along the contact of the Pennsylvanian limestones and the Red Beds, to near Purcell and then west to the Wichita Mountains; from there the party turned south to Wichita Falls, Texas, and then west across the Staked Plains and eastern New Mexico to Las Vegas. It is the portion of the trip from Wichita Falls to Las Vegas that is described in this paper.

Active work during recent years has resulted in abundant collections from the Permian or Permo-Carboniferous beds of Texas and New Mexico, and we have now a fair knowledge of the most common fossil vertebrates. New forms will undoubtedly be found and additional information gained as to the habits and structure of forms already partially known, but enough information is at hand to warrant an attempt to determine the habitat and distribution of the fauna as a whole. The work of the expedition was directed toward determining (1) the limits, both geographical and geological, of the vertebrate-bearing beds in Texas and New Mexico, and (2) the character of the beds as revealing information of the habits and habitat of the creatures.

Vertebrate fossils of Permian or Permo-Carboniferous age have been found in Cowley County, southern Kansas, in a north-south strip through central Oklahoma, in north-central Texas, and in north-central New Mexico. In Kansas, fossils have been found in only one locality and there only in the excavation of a well located at the bottom of a ravine; no exposure of bone-bearing beds has been found. In Oklahoma, fossils have been found in Kay, Grant, Noble, and Logan counties, and south of the Wichita Mountains, all in the Enid formation, but others will undoubtedly be found

wherever the Enid occurs. The lack of exposure and the abundant vegetation make their discovery a matter of great difficulty. In Texas, fossils occur in Wichita, Archer, Baylor, and Willbarger counties, and a few fragments of bone have been reported by Cummins as far south as the southern line of Haskell County, all in the Wichita and Clear Fork formations.

The Texas beds have yielded by far the greater number of vertebrate fossils and are regarded as the type locality; the relation of these beds to those of Oklahoma and New Mexico is still uncertain. On the east the Texas beds shade into the Cisco limestone as shown by Cummins and Gordon and on the west they disappear beneath the Dockum beds of Triassic age, on the eastern edge of the Staked Plains. On the western side of the Staked Plains Red Beds again appear and can be traced nearly to the edge of the Rocky Mountains, but for some distance east of the mountains they are covered, in the latitude of Las Vegas, by Cretaceous.

In attempting to answer the first question mentioned above, it was necessary to trace the Red Beds from their easternmost appearance to the edge of the mountains. The route followed was west from Wichita Falls through Seymour, in Baylor County, Haskell, Haskell County, Spur, Dickens County, Crosbyton, Crosby County, north through Floyd, Motley, and Briscoe counties to Clarendon, and then approximately along the line of the Fort Worth & Denver City Railroad to Amarillo and along the Chicago, Rock Island & Gulf Railroad to Tucumcari and Montoya. At Montoya the party left the railroad and headed for Las Vegas along the foot of the high mesa to the head of the Conchas River and then over the mesa to Las Vegas Hot Springs. The return route was across northeastern New Mexico to Clayton and then through the No Man's Land of Oklahoma to Alva where the party broke up.

Near Wichita Falls the surface rocks belong to the Wichita and Clear Fork formations already described in more or less detail by Cummins, Case, and Gordon.[1] On the east the Wichita beds shade into the Pennsylvanian limestone just as the Enid does to

[1] Cummins, *Second Annual Report, Geological Survey of Texas;* Case, *Bull. American Museum Natural History,* XXIII; Gordon, *Jour. Geol.,* XIX.

the north in Oklahoma;[1] this shows that there was to the east an open sea whose eastern limits cannot be determined as the deposits have been removed by erosion. The Wichita is composed largely of sandstones, sometimes heavily bedded, and red and blue clays sometimes with irregular shaly sandstones and local conglomerates. The Clear Fork to the west is characterized by layers of impure and dolomitic limestone distributed through a considerable thickness of irregular beds of sandstone, shale, and clay, mostly of a red color. The outcrop of the limestone is approximately along the line between Baylor and Archer counties. This formation has less of the blue clay and more of the red, with less heavily bedded sandstones, than the Wichita, but aside from the limestone the beds are so irregular in position and distribution that little can be said concerning their arrangement and, unless the appearance of the limestone be taken as a dividing line, no demarkation between the beds can be described. Farther west the Clear Fork is overlain by a series of dark-red and mottled clays with some blue and gray layers all characterized by the more regular bedding, the darker red of the clay (in general), and the presence of large quantities of gypsum in irregular seams, layers of satin spar, and thick beds of massive and semicrystalline character. Gordon found it difficult to distinguish between the Clear Fork and these beds (the Double Mountain of Cummins) and so mapped the two as undifferentiated Clear Fork and Double Mountain.[2] To the author it is as difficult to distinguish between the Wichita and the Clear Fork as it is between the latter and Double Mountain. In following or crossing the line drawn between the two last by Cummins, approximately through Haskell and Vernon, in Texas, a decided change is noticeable in the sediments. This is not to be readily detected in any limited distance or thickness. As far as Haskell the beds are similar to those found east and north of Seymour, that is, they are typical Clear Fork, with a thin but persistent layer of gray or purple conglomerate composed of small pebbles with a considerable amount of cement. This is the layer which I have previously

[1] Cummins, *loc. cit.;* Gordon, *loc. cit.;* Adams, *Am. Jour. Sci.*, XII; *Bull. Am. Geol. Soc.*, XIV.

[2] *Loc. cit.*

described as the Wichita conglomerate north of Seymour. Its persistence and peculiar character make it readily recognizable. Just beyond Sagerton, southwest of Haskell, there is a steep bluff of red clay and shales capped by a heavy sandstone just below which is a thin layer of impure limestone with large-sized, irregular ripple marks. A section taken on the east side of this bluff, locally known as Flat Top, is as follows:

| | |
|---|---|
| Gray sandstone and fine reddish conglomerate | 6–7 feet |
| Impure limestone, gray, ripple marked | 1–2 |
| Red clay with local harder layers and thin seams of gypsum | 67 |
| Shaly red clay and bluish clay | 12 |

In the lower beds are some nodules of gypsum and thin layers of satin spar.

These beds are evidently above the Clear Fork and are different in color, in the regularity and persistence of the beds, and in the first occurrence of gypsum in any quantity. Moreover, a careful search failed to reveal any bones; not even fragments in the conglomerate. Cummins found fragments of bones on Paint Creek a few miles southeast of Haskell. The country between Haskell and the exposure just described is very flat or rolling, with a smooth surface and few exposures of the rocks; there is no opportunity, therefore, to determine the line of separation between the Clear Fork and the Double Mountain and I doubt very much whether such a line could be detected in the most favorable exposure. The two series shade into each other so gradually that a sharp line of demarkation does not exist. Double Mountain time was initiated by a slow change in the sedimentation and the climate which resulted in a more regular deposition and for short and irregular periods in a great concentration of the waters. Either of these changes would render the occurrence of vertebrate fossils in the beds much less probable. West of Sagerton the surface of the country is more irregular owing to the occasional breaking-down of the capping layer of sandstone. This is especially true of the breaks on the sides of the Double Mountain Fork of the Salt Fork of the Brazos River. Just before the deeper part of the valley is reached there are several layers of impure limestone which must be considerably higher stratigraphically than the limestone seen at

Sagerton. The stream runs between steep walls of clay with abundant gypsum. On the east side of the stream near the crossing is a bluff from 60 to 70 feet high composed very largely of gypsum with thin intervening beds of gypsiferous clay. No pure selenite was found in this bluff but almost every other form of gypsum occurs: layers of splendid satin spar, impure gypsum in thin and bifurcating irregular seams, as described by Cummins, heavy beds of granular gypsum, and equally heavy beds of clusters of imperfectly formed crystals. From the dip of the beds this is evidently higher than the beds at Sagerton but it is very probable that the increase in the amount of gypsum occurs not only in the rise of the beds but also in their western extension.

Beyond the Double Mountain Fork the surface rock is a loose sandstone of considerable thickness which readily breaks down into a poor sandy soil with very few exposures on the sides of the gentle but pronounced swells. There is considerable gypsum in this sandstone, as shown by the frequent efflorescence and beds of pulverent calcium sulphate. True beds of gypsum do not appear again until the hills beyond Aspermont are reached; here at a much higher level than the gypsum on the banks of the Double Mountain Fork, there occur layers, several feet in thickness, of pure granular gypsum, so soft that it is deeply marked by grooves due to rills of rainwater.

At Double Mountain, a few miles southwest of Aspermont, the following section was made by Dumble and Cummins:

| | | |
|---|---|---|
| Lower Cretaceous | Caprina limestone | 40 feet |
| | Comanche Peak series | 55 |
| | Trinity | 25 |
| Triassic | 3*a*. Dockum | 35 |
| Permian | Shaly clay underlaid by red or terra cotta sandstone | 105 |
| | Upper gypsum beds | 60 |
| | Middle gypsum beds | 75 |
| | Lower gypsum beds | 135* |

* *Am. Geol.*, 1892, p. 348.

The author's section agrees in only a general way with the portion marked Permian, unless it be understood that the gypsum beds be considered to mean red clay with much interspersed gypsum. Double Mountain is an outlier of the Staked Plains and

shows the easternmost appearance of beds which can be referred to the Triassic. The reference is without paleontological evidence, but there is certainly a bed of disturbed sandstone and sands which fill a gap between the Permian and the Cretaceous. West of Double Mountain the comparatively level surface is continued to the breaks of Blanco Canyon west of Spur in Dickens County. Just east of the point where the road from Spur to Crosbyton crosses the Blanco Canyon there is a small tributary

FIG. 1.—Contact between the Dockum (Triassic) and the Double Mountain (Permian) beds near Blanco Canyon. The tilted layer just opposite the figure on the left marks the line of contact.

of the canyon; the road crosses this tributary on a layer of hard, bluish-green sandstone which is apparently near the dividing line between the Triassic and the Permian (see Fig. 1); above it are the sands and clays of the Dockum, as attested by the plant and vertebrate remains, and below it is a break indicated by a stratum of tilted sandstone which in turn lies upon sandstones and clays of the Double Mountain.

A general section of the Triassic at this point is as follows:

| | |
|---|---|
| Fine cross-bedded conglomerate, variable in thickness | 5–20 feet |
| Red clay shading into yellow above | 40–60 |
| White, red, and maroon clay | 20–40 |
| Light-brown clay shading into a white clay with gypsum, plant remains, Unio and Triassic vertebrates | 10–30 |
| Bluish-green sandstone | 3–4 |
| Cross-bedded and tilted sandstone and red clay of the Double Mountain formation | 10+ |

The discovery of Triassic vertebrates in the white clay confirms Cummins' location of the Permian-Triassic line at this point. Just below the bluish-green sandstone which is regarded as the base of the Triassic there is a layer of steeply tilted sandstone which marks a decided disturbance, perhaps of only local significance. Beyond Blanco Canyon the Triassic continues to the base of the Staked Plains and is covered by the Tertiary, the lowest portion of

FIG. 2.—Contact between the Dockum (Triassic) and Double Mountain (Permian) beds on Mott Creek. Above the head of the pick is a light-yellow cross-bedded sandstone; below is a solid red clay.

which is a gravel containing many water-worn shells of Gryphea and Ostrea. The red is again seen in the Blanco Canyon. Where the party descended into the canyon a few miles southeast of Mount Blanco the white Tertiary is underlain by a pink or reddish deposit of clay which is probably of Tertiary age and composed of reworked Triassic material. Below this there is undisturbed red clay, probably of Triassic age, though no fossils were found in it. Beyond Blanco Canyon, in the vicinity of Lyman in Motley County, the

party worked its way into the valley of Mott Creek and followed down the creek to Conleys Peak near White Flat. This creek heads in the Tertiary, producing a very rough topography of characteristic Tertiary bad lands; below this is a wide terrace of coarse gravel and conglomerate carrying water-worn Cretaceous fossils. Below the terrace is a series of red clays and sandstones, the latter much cross-bedded and disturbed; in certain local layers of limy

FIG. 3.—Triassic beds on Salavito Creek. Gray clays and sandstones capped by heavy gray and red sandstone.

material Unios and fragments of Phytosaur bones were found in the sandstone, determining the Triassic age of the beds. On descending Mott Creek the disturbed Triassic beds are seen to lie upon a series of red clays, very dark in color and evenly bedded, very similar in appearance to the Double Mountain beds farther east and south. The physical characters are far from being a dependable character for correlation in the Red Beds, but taken in connection with the sudden change in character, the striking unconformity, and the correct stratigraphic position these are very probably the same, Double Mountain, beds as seen east of Spur.

From Mott Creek the party again ascended to the surface of the

Staked Plains at Quitaque and then made its way to Clarendon across the Red River, or the Prairie Dog Fork of the Red River, as it is marked on the maps. This region has been described by Gould in *Water Supply Papers 154* and *191* and needs no further description. It appears to me from our section and almost continuous tracing of the beds that there can be no doubt that the horizons called Quartermaster and Greer in the eastern and western portions

FIG. 4.—Triassic beds in the Bad Lands of Trujillo Creek, east of Tucumcari. The capping sandstone and conglomerate is the same as that which forms the surface of the shelf extending north from the foot of the Staked Plains.

of the Panhandle by Gould are the same as the Double Mountain beds farther south.

From Clarendon the party went to Amarillo and then followed the Chicago, Rock Island & Gulf Railroad across the Staked Plains to the western edge. Here the red again appears in irregular beds of sandstone and varicolored clays extremely irregular in thickness and extent but carrying Phytosaur bones wherever seen. In the breaks of the small Arroya Salavito just beyond Endee in Quay County, New Mexico, the beds are even more than ordinarily complex, massive white and gray sandstones lie above cross-bedded white and gray sandstones and clays, but here again fragments of Phytosaur bones and teeth were found. The main object of the

trip from this point west to the mountains was to detect any recurrence of the Permian Red Beds, but, as will be shown, nothing below the Triassic was found.

Farther west the breaks of San Juan Arroya or Trujillo Creek are locally known as the Bad Lands; here there is a very considerable exposure of Red Beds. The beds, as in Salavito Arroya, are considerably below those which are exposed in the bluff forming the

FIG. 5.—Larger view of the pillar shown in Fig. 4. The light-blue layer of sandy clay is seen just below the conglomerate cap. Below is red clay.

western edge of the Staked Plains a few miles to the south. A layer of heavy sandstone and conglomerate, varying rapidly in character, but as a whole very persistent, determines a shelf extending north from the foot of the plains and covered with grass. It is only in the valleys of the streams that it is broken through and the lower part of the section exposed. A short distance to the north the streams run out upon the shelf which is not again broken until the breaks of the Canadian River to the north are reached. A

section of the upper portion of the Triassic taken on the west side of the plains just west of Adrian is as follows:

| | |
|---|---|
| Tertiary marl | 6–20 feet |
| Fine white sandstone | 20 |
| Red clay | 10 |
| Red sandstone or hard sand | 12–15 |
| Dark-red clay containing a layer of variable sandstone and conglomerate | 20+ |

It is the conglomerate at the base of the section which forms the top of the shelf described above; it rises and falls in the layer

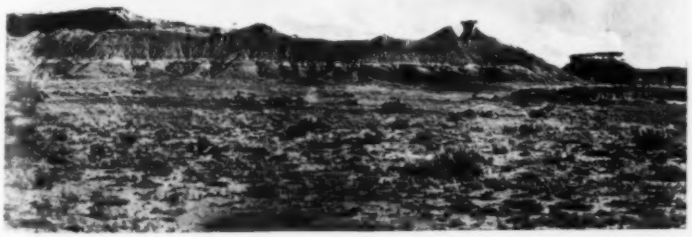

FIG. 6.—Variegated clays of Triassic age in the Bad Lands of Trujillo Creek. The remnants of the conglomerate cap may be seen. The clays are red, purple, and light orange.

of clay and changes its character very suddenly, being strongly reminiscent of the conditions in the Clear Fork beds. In the breaks of the streams mentioned above the conglomerate forms the top of the section. A general section in the Bad Lands of Trujillo Creek is as follows:

1. Conglomerate (top). Grayish in general, but locally reddish and overlain by red sandstone in places. The pebbles variable in size and character. Some thin layers of clay and shale. In places replaced by sandstone (in one place a true arkose).

2. Thin, blue, sandy clay; very persistent just beneath the conglomerate and frequently much distorted, apparently by local movements due to pressure. From 6 to 12 inches thick.

3. A heavy bed of red clay of varying shades and some blue streaks. Generally very homogeneous but with some layers of calcareous material. Near the bottom some shaly layers with worm casts. Two hundred and fifty feet thick, more or less.

4. A second series of sandstone and shaly layers. Bottom not seen, but Triassic bones to bottom of exposures.

FIG. 7.—A remnant in the Bad Lands of Trujillo Creek. Just below the conglomerate cap may be seen the layer of bluish sandy clay, just over the figure. Below the bluish layer the clay is purple, which shades downward into bright red.

The lower beds may be traced to Tucumcari and Montoya, the road lying upon the shelf described above. At Mount Tucumcari and in the magnificent section seen in Bull Canyon, just south of Montoya, it is the upper portion of the Triassic which is exposed. A slight anticlinal fold at Montoya brings some of the lower beds to the surface, but even here Phytosaur bones were found in the lowest exposures.

From Montoya the route of the party led along the foot of the mesa to the head of the Conchas River. The sandstone or con-

glomerate followed from farther east forms the floor of the valley; the upper part of the Triassic is exposed in the walls of the mesa beneath the capping of Dakota Cretaceous and the Morrison formation (Lee), and the lower part is seen in the valleys of the streams. Beyond Cabra Spring (a single ranch house located near the middle of the Corazon Topographic Sheet) the Conchas River

FIG. 8.—Red clay in the walls of Bull Canyon just south of Montoya. This is the portion of the Triassic above the conglomerate layer which forms the shelf extending north from the foot of the Staked Plains.

has cut a deep gorge through the heavy sandstone and conglomerate into a heavy bed of white sandstone (40–50 feet) of a local character. Beneath and partly within this sandstone is a lense of dark-red and mottled clays and shales, much distorted and streaked with greenish clay and a greenish conglomerate of small pebbles. This is the lowest bed of the Triassic that was seen and it so much resembles the Double Mountain that I at first thought that it must be Permian; but the discovery of Unios in the layer of greenish conglomerate revealed its Triassic age. This makes it altogether probable that nothing below the base of the Triassic appears between Montoya and Las Vegas.

Ascending to the top of the mesa by the difficult road at the

head of the Conchas Canyon, the party proceeded to Las Vegas Hot Springs. Here the red again appears in vertical layers on the edge of the mountains. This class of exposures is obviously an exceedingly unfortunate one in which to search for vertebrate fossils. The Red Beds had been lost when we ascended to the top of the mesa from the Conchas Canyon, but the nearly horizontal

FIG. 9.—Clays, sandstones, and impure limestones in the wall of Bull Canyon just south of Montoya. Contrast the horizontal condition of the beds in this the upper portion of the Triassic with the disturbed condition shown in the lower beds (FIG. 3).

condition of the beds in the sides of the mesa and the Cretaceous cap leave little possibility of doubt that the beds turned up on the sides of the mountains at Las Vegas Hot Springs are the same as those we left a few miles to the east. On the Geological Map of the United States the Red Beds on the flanks of the mountains are called Permian. Girty examined the beds at Las Vegas Hot Springs but was unable to determine their age. A day's careful search by the author in the vicinity of Las Vegas Hot Springs

resulted in the finding of a single broken tooth in a conglomerate near the middle of the series; as this is a Phytosaur or Dinosaur tooth it shows that the upper half of the beds, at least, is Triassic. Whether any of the beds below this belong in the Permian it is still impossible to say, but when we consider the great thickness of the Triassic not very many miles to the east it is not likely that Red Beds of Permian age have any considerable thickness, if they are present at all. Moreover, it can be shown that the Permian beds

FIG. 10.—Wall of the mesa near the head of the Conchas Canyon. The capping layer is Dakota beneath which lie the beds considered by Lee as Morrison. The lower heavy layer is the uppermost layer of the Triassic.

north of Santa Fe were laid down in an area of deposition completely separated from that over Texas and Oklahoma. I am inclined to suggest that the sea or area of deposition which covered northern and western Texas and Oklahoma had its western border somewhere east of the present Rockies and that the Red Beds on the eastern flanks of the mountains in northern New Mexico and southern Colorado, at least, have no Permian members.

It will be seen from the foregoing that the evidence from vertebrate fossils bears out in a pretty conclusive manner the conclusions drawn from stratigraphic evidence. The Clear Fork beds, with their vertebrate fauna, disappear beneath a distinct set of beds, the Double Mountain, at about the line of Haskell. Just how much farther west they go it is impossible to say, but it is not far. In western Texas and eastern New Mexico, along the line followed,

they are deeply buried beneath the Triassic and most probably do not appear on the flanks of the Rockies. The change from the Clear Fork to the Double Mountain was a very gradual one but sufficiently profound to render the presence of fossils in the beds or of animals in the region during the time of deposition (the two things are very different) almost impossible.

The contact between the Triassic and the Double Mountain is marked in several places by sharp unconformities, but the beds are

FIG. 11.—Vertical beds of Triassic age on the south side of the small valley at Las Vegas Hot Springs.

so irregular above and below that it is impossible to evaluate the unconformity. It is certain that after a period of erosion or exposure conditions of sedimentation closely resembling those of the Clear Fork followed the more uniform conditions of the Double Mountain. That this interval was long is suggested by the totally new fauna contained in the beds, but this is not conclusive. The fauna may have been evolving during the Double Mountain time or may have started even earlier and reached this region by migration at the beginning of the Triassic.

The sediments of the upper part of the Permian were undoubtedly derived from some not very remote land mass but the outlines

of this cannot as yet be suggested. Undoubtedly the Wichita Mountains furnished much of the sediments of the Texas and Oklahoma beds, but where the western land mass lay and what were its limits are yet uncertain. Many suggestions have risen as to its possible outlines but the discussion of the evidence is beyond the limits of this paper.

# PLEISTOCENE VULCANISM OF THE COAST RANGE OF BRITISH COLUMBIA

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During the present summer the writer had occasion to visit the Mount Garibaldi region of the Coast Range of British Columbia, which lies about forty miles due north of the city of Vancouver, between 49°40′ and 50° north latitude and on the 123d meridian of west longitude. The approach to this district is by way of Howe Sound, a typical fiord, and the valley of the Cheakamous River. The volcanic origin of Mount Garibaldi, the highest peak in the region, had been recognized by members of the British Columbia Mountaineering Club, who made the first ascent of it some six or seven years ago. The region to the north of Garibaldi as far as the Black Tusk Mountain was subsequently penetrated for the first time by Mr. W. J. Gray, in whose company the present writer had the advantage of visiting the locality. The general situation, as far as it could be determined in a few days' study, is as follows:

## I. PHYSIOGRAPHIC AND GLACIAL HISTORY

The Cheakamous River flows into the head of Howe Sound through a valley whose general trend is the continuation of that of the sound itself and lies in a north-northeast direction. The mountain-mass known as the Garibaldi Range lies to the eastward of it. At a point about twenty-five miles from tidewater the Cheakamous receives on the eastern side a tributary which is known as Stony Creek whose valley affords a convenient means of access to the higher parts of the range. Commencing with the bottom of the Cheakamous valley, the following features are to be observed as one ascends the range:

1. *Post-Glacial gorge*, in which the Cheakamous at present flows, cut through glacial deposits and in part through the rock to a depth of at least 300 feet.

2. *Main valley of the Cheakamous*, which has a total depth approaching 4,000 feet, and consists of well-marked inner and outer valleys. Both of these are glaciated parallel to their length. The outer valley is represented by a terrace at least a mile wide on the eastern side, and some 3,000 feet below the rim of the valley.

3. On reaching the upper edge of the valley one emerges at about 5,100 feet elevation, on a plateau, which has been dissected into broad, flat-topped spurs by the streams tributary to the Cheakamous. The surface of the plateau slopes upward to the east at an angle of from 7° to 10°, which increases toward the east, and an extension of the plateau surface probably forms the summit level of the range, at an altitude of about 8,000 feet. Incised in its surface are the remains of one or two older valleys which once ran parallel to the Cheakamous, but have since been cut across by the tributaries of that stream, and appear as notches crossing the intervening spurs. The age of this plateau is indicated by the fact that two ridges rise above it whose summits consist of remnants of andesitic lava flows, probably of early Miocene age. These flows originally probably filled valleys. The floor upon which the flow rested is now in one case, the Black Tusk Ridge, at least 1,200 feet above the plateau-surface below, while in another case, near Table Mountain, the columnar andesite itself forms a part of that surface. The end of the erosion-cycle which was responsible for the plateau can therefore hardly be earlier than Pliocene or late Miocene. On the other hand, both the plateau-surface and that of the ridges above it bear striae of the earliest glaciation of which record remains. The ice during this time covered the range up to a height of at least 6,500 feet as a sheet, whose general movement in this locality was S.S.W., or parallel to the trend of the main valleys. The plateau may therefore be assumed to be pre-Pleistocene. It is composed of rocks of Palaeozoic (probably Devono-Carboniferous)[1] age, of the subsequently intruded (Upper Jurassic) granites of the Coast batholith, and, as already explained, in some parts of the Miocene andesites. The tributary valleys which dissect it end in cirques in the upper part of the range, which are for the most part still occupied by glaciers. These valleys are of considerable depth, in one case

[1] See O. E. LeRoy, G.S.C., *Publication No. 996*, 1908.

over 1,800 feet. Many of them are hanging valleys as regards the Cheakamous valley. They exhibit well-marked evidences of the second epoch of glaciation, which was merely an extension of the existing glaciers which filled the valley-system, including the main valleys, but did not override the range in a continuous icesheet.

## II. VULCANISM

Superimposed upon the topographic featues which have been described are the andesitic cones and lava flows, which are unglaciated by the earlier icesheet, and only partially so by the later ice-advance. The volcanic foci which have been visited up to the present are three in number, but other peaks visible to the northward seem to be undoubtedly of similar origin.

Mount Garibaldi, the largest of the group and also the most southerly, is the highest peak in the region. Its summit is 8,700 feet above the sea, from which it is about 12 miles distant. It stands about 3,500 feet above the plateau. It is so surrounded by glaciers and snowfields that a study of its relations to the underlying terranes is impracticable, except possibly on the western face where freshly-cut ravines may expose sections. The walls of the cirques which have been cut into its sides afford admirable sections of the cone itself. The materials of which it is composed are of a light reddish-brown color, and appear to be largely fragmental. Lava streams extended down into the inner Cheakamous valley, where remnants of them may be seen along the Lilooet road. The proximity of the cone to the valley and the somewhat loosely coherent nature of the materials of which it is composed have rendered dissection somewhat rapid, and the conical symmetry has already been lost to a considerable extent, while the crater can only be doubtfully identified.

Situated about 5 miles to the north of Garibaldi, on the western margin of the lake of the same name, is the double volcanic cone known as Red Mountain, which has an elevation of about 1,000 feet above the plateau, or 6,500 feet above sea-level. As this volcano is much more easily accessible than Garibaldi, and practically free from snow, a fairly complete view was obtained of it. The volcanic cone stands within a cirquelike basin cut into the

plateau on the south side of the valley of Garibaldi Lake. This basin consists of a wall of granite, inclosing the cone on its west and southwest sides and a summit standing out on the east side of the cone which is composed of the older Miocene andesite. This also appears to form the floor upon which the volcano stands. This basin is probably a glacial cirque. It is now almost completely filled up by the volcano, but some small areas of its floor which are exposed on the north side appear to have been almost certainly

FIG. 1.—Mount Garibaldi and Red Mountain from the north. Garibaldi Lake in the foreground. The lava flow which dams it is to the right, beyond the picture. The old trunkated flow described is in the foreground. The flat-topped mountain in front of Mount Garibaldi is Table Mountain, which is composed of Miocene lavas.

glaciated. It might otherwise have been attributed to explosive action in the early stages of the vulcanism, but there are no fragmental materials around its margin which would confirm this. The inner wall of the basin shows no evidence of glacial polishing, while the plateau above is well striated by the first glaciation. The basin seems, therefore, to have originated at a time later than the first glaciation, and is probably a cirque formed during its retreat or during the second period of ice-advance. The beginning of the volcanic activity must therefore also be dated subsequent to the first glaciation and perhaps later than the beginning of the second glaciation, if time must be allowed for the formation of the cirque. Neither of the two cones show any evidence of having been overridden by ice at any time. The older cone lies to the east. It is

more largely composed of fragmental materials than the western one, which is essentially a lava-cone. The older cone contains much material derived from the underlying rocks, especially fragments of granite and the columnar Miocene andesite which exhibit evidences of the high temperature to which they have been exposed within the vent. In the case of the granite the result is a general softening and tendency to disintegration, while the andesite blocks show cooling cracks which extend some distance from their surfaces inward.

That there was a still earlier cone which has been destroyed is proved by the remnant of a large lava-stream on the nothern side of the older remaining cone, the upper part of which has been cut off so that it presents a precipitous face, inside of which the older of the present cones has been built up. The cones as they now stand are therefore later than that from which this lava was extruded. The lower part of this old flow descended into the valley of Stony Creek, now occupied by Garibaldi Lake, but has been eroded away, probably by the glacier which occupied the valley during the second period of glaciation. This would indicate that the period of activity of this volcano extended back into the later of the two glacial epochs.

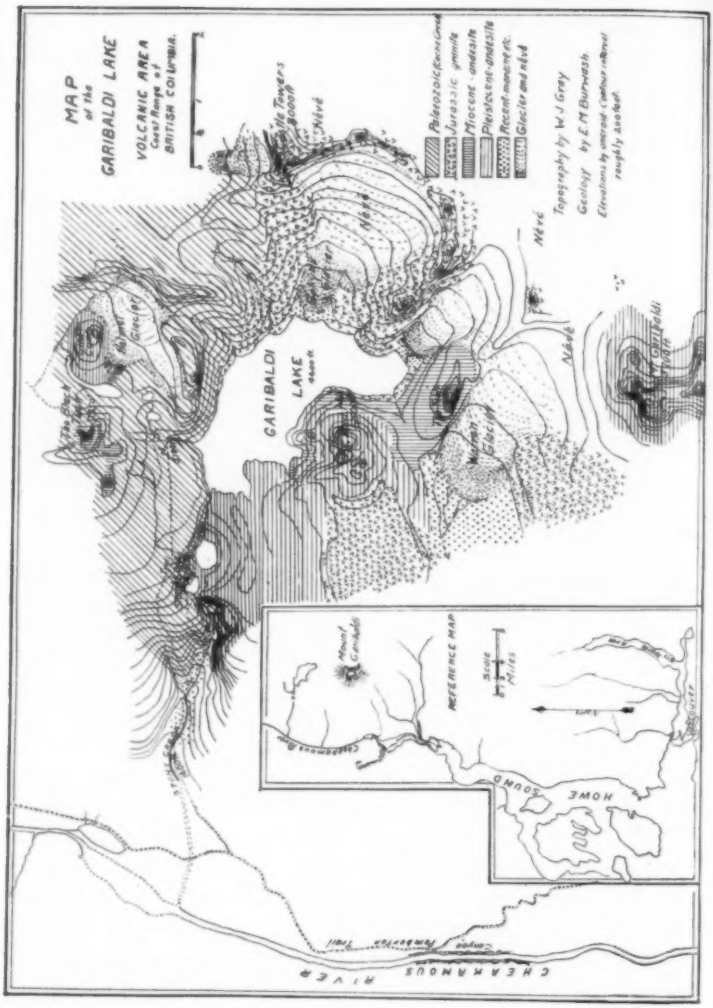
There is, on the other hand, abundant evidence that vulcanism continued for some time after the ice had retreated nearly to its present limits. Lava-flows from the western crater of Red Mountain have filled Stony Creek valley for a distance of about a mile and a half, and their surfaces are entirely unglaciated. The resultant damming of the creek has produced Garibaldi Lake, whose waters now find their outlet along a channel between the edge of the lava-flow and the northern wall of the valley until they reach a recess in the lava which forms the basin of Lesser Garibaldi Lake. From this point onward the stream follows a subterranean channel under the lava flow, beneath which it reappears at the foot of the cliff known as "the Barrier," which has been formed by the undercutting of the lower end of the lava-flow. At times of exceptionally high water, a part of the stream flows over the surface to Stony Lake, and thence over the Barrier into the lower valley. The cutting away of the lava here has exposed a section of the flow,

which can be seen to rest upon glacial till, and upon rock surfaces which bear striae belonging to both periods of glaciation. These later lava-streams are therefore undoubtedly post-glacial. Their surface is covered with a well-grown forest.

A small cinder-cone, some 500 feet in height, about four miles north-northeast of Red Mountain, is the most northerly volcanic vent examined. It stands in the mouth of a large cirque which faces the north and opens upon a valley known as Desolation Valley. This is an abandoned glacial hanging valley and con-

FIG. 2.—Cinder Cone in Desolation Valley. The cone is in the middle distance covered with dark bushes. To the right is a snow-field, and one of the glaciers discharging from it beside the cone. In the left foreground are a small lake and the outwash-delta of the glacial stream. The ridge which bounds the snow-field forms the background.

tains a number of lakes. Its floor is about 5,350 feet above sea-level. The cirque contains a large snow-field, whose lower edge rests against the side of the volcanic cone and discharges by a glacier on each side of it. There is evidence that the ice at one time overrode parts of the cone which are now free from it, and probably filled the valley on the north side of it since the volcano was active. A small lake lying in the valley is rapidly being filled by a delta of outwash from the glacier, most of which consists of volcanic materials. A glacial stream which flowed over the western part of the cone from the snow-field behind it has cut a ravine in the flank of the cone in which a cross-section of the faulted tufaceous strata is well shown. The summit is 5,850 feet above sea-level and the cone has a crater about 70 feet deep, which was partially filled with water at the time of our visit.


MAP
of the
GARIBALDI LAKE
VOLCANIC AREA
East Range of
BRITISH COLUMBIA
Mt. Tantalus
Névé
Névé
Névé

The age of this cone appears to correspond with that of Red Mountain. Neither can be said to have originated as far back as the first glacial period. In the tills, however, which represent the end of that period in the Capilano Valley, near Vancouver, there are blocks of the reddish andesitic lava which is characteristic of this period of vulcanism. This locality lies south of Mount Garibaldi, and could only be reached by ice of a general glaciation, moving over the summits of the higher ridges. It is probable, therefore, that Mount Garibaldi is of considerably earlier date than either of the smaller vents to the northward, and that the lava erratics of the Capilano Valley may be referred to the early eruptions of Mount Garibaldi. This would also agree with the extensively dissected condition of the Garibaldi cone as compared with the others. The total time-range of the vulcanism would therefore extend from early Pleistocene through a considerable part of the Recent, if we suppose the earliest recorded glaciation to have been in fact the earliest of the Pleistocene ice-ages. In any event, we must place the beginning of the vulcanism well back in the Pleistocene.

The nature of the lavas, which are reddish-brown andesites and andesite-porphyries indicates a lithological relationship with the Pleistocene volcanics of the Pacific coast states. The zone of activity is thus extended from Mount Baker in a north-northwest direction for about 100 miles, and into a quite new geological province, that of the Coast Range batholith.

# DIASTROPHISM AND THE FORMATIVE PROCESSES. VI

## FORESET BEDS AND SLOPE DEPOSITS

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Nearly all marine sediments are carried to their resting-places in one or another of three general ways: (1) by rolling or sliding down relatively steep slopes, where gravity is the chief factor and the agitation of the water only an auxiliary agency; (2) by being forced along low slopes where agitation and currents are essential factors; and (3) by flotation, where the relative levity or fineness of the material is an essential factor. These are conveniently called (1) foreset beds, (2) topset beds, and (3) flotation beds. If we may use these terms in a rather free and broad sense, based on the dominant feature, with neglect of intergradations and alternations, it will be convenient to speak of the shelf-sea deposits as topset beds, of the deposits of the abysmal slope as foreset beds, and of the deep-sea deposits as flotation or bottom-set beds, though flotation contributions enter in notable measure into the composition of both the other classes.

The abysmal deposits were the subject of our last discussion, and in earlier articles the shelf-sea deposits were under study. It remains to see, so far as we may, what bearings on diastrophic problems the foreset beds have, taking as our leading type those that lie on the abysmal faces of the continental terraces.

These foreset beds are formed of a coarser and a finer element. The coarser embraces material that has been rolled or pushed by stages over the upper face of the continental shelves until the oceanward edges of these were reached, beyond which the material has descended the steeper slopes under degrees of agitation of milder sorts than those required to move them over the upper face of the shelves. These materials may be said to be the overflow of the topset or shelf-sea beds. As these slope deposits are gradually

built out, they serve as a causeway on which the topset beds are advanced seaward.

The finer element embraces those portions of the silts from the land that were light enough or fine enough to be kept in suspension—or to be stirred up frequently into temporary suspension—by the agitated waters of the shelf-seas and so borne oceanward continuously or by stages. They were, however, insufficiently comminuted to float long and so to reach the central ocean areas and find lodgment in the true abysmal depths. This element in general is intermediate between the coarser flotation material which settles and remains on the sea-shelves in spite of considerable agitation, and the extremely fine silt that reaches the heart of the ocean and enters into the deep-sea deposits.

The many obvious qualifications of these broad statements need not detain us here for we are seeking chiefly the relations of these formative processes to problems of diastrophism. The matter of first special interest in this relationship concerns the thicknesses of the foreset, the topset, and the flotation beds respectively and the inferences drawn from these thicknesses. It is common practice to regard the thickness attained by any series of beds prior to a deformation, as a measure of the subsidence of the crust, if evidences of agitated water or shoal life occur at various horizons in the series. This inferred subsidence, when large, is often thought to have invited a deformative movement. Theories of the cause or of the localizing agency of deformations have been hung on such supposed proof of deep subsidence. Appeals have been made to a rise of the geotherms supposed to be consequent upon subsidence. Even softening or melting of the under crust has been deduced from such depression. When the series is thick and shows abundant evidence of shallow-water action at nearly all horizons, these features have been regarded as proof of such deep subsidence, and the proof has been felt to be quite irrefragable. Few tenets of geology have a firmer hold on the convictions of working geologists or have seemed more nearly axiomatic. If the trustworthiness of this tenet is to be called in question, in any sense, or in any degree, the grounds for so doing should be clear.

Flotation beds may be laid down in strict horizontality, and on

slopes of various moderate degrees as well. Sediments that come into place only by sliding or rolling usually require a declining gradient. It is admissible to regard the abysmal beds, looked at broadly, as essentially horizontal. Additions to them are made by sheets of flotation sediment falling from above with some approximation to uniformity. The thicknesses that may be attained by such beds in the ocean, so long as the crust maintains a static condition, are strictly limited by the depth of the ocean. This seems a mere truism and falls in with the instinctive inferences that have given rise to the common conviction.

It is, however, admissible, if not imperative, to regard the sea-shelves as sloping from the continents oceanward, and to recognize that in the very nature of their formation, they persist in sloping systematically toward the ocean at all stages of their formation when they are built up normally. The slopes on the present continental shelves vary through a considerable range. The precise slope is not a matter of special moment in this paper, though it is important in special problems. It will serve our present purpose to recognize slopes as being often as low as three feet per mile and often as high as twelve feet per mile, or from 1 in 1,760 to 1 in 440, while both lower and higher slopes are not uncommonly observed. For this discussion let us take the conservative figure of four feet per mile, or 1 in 1,320, as representative. While it is not here important to assume one approximate figure rather than another, it is important to recognize that some such slope is a systematic feature of the shelf-sea deposits in their normal state, that it is inherent in the nature of the case, and that it may safely be presumed to have affected the sea-shelf deposits of all periods.

At the oceanward edge of these slightly sloping shelves, the topset beds join at an angle or curve the foreset beds that form the steeper abysmal slope. While the dips of the foreset beds have large variations, they are usually much higher than the topset beds and this higher dip is a systematic feature. Such higher dips must be presumed to have affected the foreset beds in all stages of shelf growth and to be a persistent feature. Willis generalizes the commoner angles of the present abysmal slopes at 2° to 5°, which may be translated, roundly, into 1 in 30 to 1 in 12, but much higher and

much lower slopes occur. These slopes vary with conditions, as in the case of the topset beds, but, in the nature of the case, they persist at some grade so long as there is continental feeding and effective shelf-sea action.

If now the picture of the slopes of the topset and of the foreset beds of the continental shelves, and their relations to one another, are clearly in mind, and it is plainly seen that they are persistent and systematic features, we are prepared for the question: What is the limit of thickness of foreset and topset beds in an ocean of given depth where no subsidence or creep takes place? As thus stated, no determinate answer to the question is possible. The depth of the ocean—beyond a sufficient working depth—is essentially immaterial so far as the theoretical possibilities of thickness are concerned. It is rather the *breadth* of the ocean than its *depth* that controls the possible thickness of such sloping beds. *The growth of the continental shelves oceanward increases the thickness of the topset and foreset strata irrespective of the ocean depth.* The ocean depth merely determines the amount of material required to effect the oceanward growth. While it may thus influence the rate of growth in thickness or the ratio of topset beds to foreset beds, or their slopes, or other details incidental to thickness, it is not vital to the possibilities of thickness.

If all this is not evident from the mere statement of the case, it should become so from an inspection of the accompanying figure in which it is assumed that the crust remains absolutely stationary, that there is a continual supply of material from the land, that the sea surface changes only as it is forced to rise by sea-filling, that the depth of effective shelf-sea action is 100 fathoms, and that a normal distribution of sediment arises from the movements of the sea-water. According to standard methods of finding the thickness of beds, the measurement is taken on lines normal to the deposition planes. This is obviously the correct method, as it sums up the successive increments of sedimentation. It will be seen from the diagram (Fig. 1) that the topset and the foreset beds increase by the addition of layer laid obliquely upon layer in the course of the growth seaward and that these lie in essentially the same horizon and may accumulate quite irrespective of the total depth of ocean.

A growth of the continental shelf seaward to the extent of 1,000 miles would increase the sum of the thicknesses of the topset or sea-shelf strata to the amount of 4,000 feet, if the shelf slope were constant at 1 in 1,320; while the sum of the foreset beds on the abysmal slope would increase to 176,000 feet, if its inclination remained constant at 1 in 30, i.e., constant at a slope of about 2°. The thicknesses of topset beds under the range of slope given above would vary from 3,000 feet to 12,000 feet and of foreset beds from 176,000 feet to 440,000 feet. In all this, it is assumed that there is absolutely no subsidence of the crust, nor creep, nor diastrophism of any kind, nor any change of any kind, except what may be involved in keeping up a supply of terriginous matter and in maintaining normal

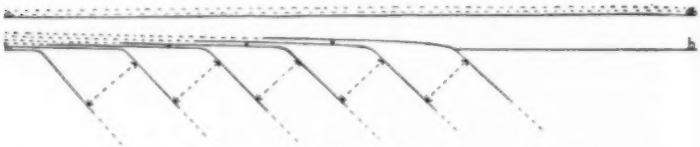


FIG. 1.—*aa*, sea level; *bb*, limit in depth of effective surface action; crust stationary; creep absent; silt supply constant; action strictly normal; slopes exaggerated.

sea action on the shelf, and so maintaining a systematic growth seaward.

From this it is easy to see that, given a sufficient supply of material and a continuance of normal action and static condition, it would be possible for normal processes to build out into the ocean a series of foreset beds that would sum up a thickness much exceeding the whole geological column, without the slightest subsidence. Even the sea-shelf beds in such a case would attain a very impressive sum of thicknesses.

In these statements, it is assumed that thicknesses are measured in the standard way, bed by bed, at right angles to the bedding planes.

Under the perfectly stable conditions named, and on the assumption that the angle between the topset and foreset beds of the continental shelf was maintained at 100 fathoms below the sea surface, the series of shelf-sea deposits would never have a vertical depth of

more than 600 feet plus the rise of the sea-level due to filling, but, *because they lie inclined upon one another*, the sum of their individual thicknesses may have reached the impressive figures indicated. So also, under these conditions, the vertical depth of the foreset beds would never equal the depth of the ocean, but the sum of their individual thicknesses might many times exceed its greatest depth.

Under the conditions named, the shelf-sea or topset deposits should bear abundant evidence of a shallow water origin at all horizons, since none were formed at a greater depth than 600 feet, plus the rise of the sea-level, and yet their stratigraphic thickness measured in the usual way, the correct way, might rise to some thousands of feet without the slightest subsidence.

Under the same conditions, the upper edges of the foreset beds, or beds of the abysmal slope, might show evidences of sea agitation and the special marks of currents actuated by winds and tides, and they might be filled with fossils that lived within a thousand feet or so of the sea surface. These evidences of somewhat shallow water might affect the upper edges of tens of thousands or hundreds of thousands of feet of inclined beds measured in the usual correct way. Farther down on the abysmal slope the beds would of course carry life implying deeper water, and at still greater depths there would be a gradation toward, and finally into, true abysmal deposits.

It is immaterial whether the sediments are inorganic or organic so long as the comminution is such as to permit transportation in one or another of the three usual ways. Coral sand and silt are as susceptible to sloping sedimentation as siliceous or silicate sands and silts, and perhaps as frequently take on sloping attitudes. The depositional dips of corraline limestones are often of pronounced order. Calcareous sands and silts from any organic source, foraminal, algous, and bacterial included, are susceptible of deposition on either topset or foreset slopes, and so beds of limestone or dolomite may alternate with other topset beds or foreset beds in normal sloping terranes.

The principles of stratification, and of stratigraphic interpretation, thus systematically embodied in the outward growth of the continental shelves, are likewise embodied in the growth of shelves

from the borders toward the interiors of the smaller water-filled basins, whether these smaller basins arise from diastrophism or from any other source, and whether they are indentures of the borders of the continents or lie within them as mediterranean basins. In these smaller basins the shelves are usually narrower and the slopes are liable to be higher because the backward distribution of the sediments is less effective since the surface agitation and the circulatory currents are generally feebler, but this difference of slope is not inevitable nor universal.

There is this further difference, that in the intra-continental basins the land surrounds the water bodies and they are, in an areal sense, the minor elements, while the oceans surround the continents and, in an areal sense, are the major elements. In the intra-continental basins, the feeding areas are generally large compared with the depositional areas. The growth of the terraces is centripetal and their borders constantly diminish, while the growth of the circum-continental shelves is centrifugal and their borders constantly increase. While these are only features that have a quantitative bearing, they are worthy of passing notice because by far the larger part of the subaqueous strata that have been studied in detail by geologists are of the intra-continental or epicontinental order. The study of the circum-continental growths is a field to which less ample attention has been directed.

Before the foreset beds are left, some special features may well be considered but they are reserved for a later article.

DUPARC, LOUIS, et MONNIER, ALFRED. *Traité de technique minéralogique et pétrographique.* Vol. II-1. *Les méthodes chimiques qualitatives.* Leipzig: Veit & Co., 1913. Pp. xii+372, figs. 117, colored plate 1.

This volume, the second of the series, deals with qualitative chemical methods for the determination of minerals. A third volume on quantitative methods is to appear shortly.

The author discusses first the processes of separating the mineral constituents of a rock, or a mineral from its impurities, by means of sliming, heavy solutions, the electro-magnet, and chemicals. The microchemical reactions are next treated. It would have been desirable, from a petrographical standpoint, had the authors discussed these methods more fully than in the 27 pages here given. While much work has been done by Behrens, Streng, Brauns, Haushofer, and others in the determination of the elements, no one, since Boricky, has fully taken up the work from the mineralogist's side.

The methods for blow-pipe determinations are given from the chemical, rather than from the mineralogical side, since the determinations are for the chemical elements. To the preparation of solutions of minerals preparatory to chemical analysis, 19 pages are given. Following this there are 196 pages of chemical reactions of the different elements. This is very complete, all the methods which have ever been employed for the identification or separation of the elements being given. There are also 60 pages of spectroscopic methods and 5 of determinations of radioactivity.

The last chapter is devoted to the rapid determination of minerals by the examination of certain chemical characters. The authors here closely follow von Kobell's tables.

A good index is added, something which was greatly missed from the first part.

The book is an important and needed contribution to the chemical side of mineralogy. It is uniformly bound with the first part, in half leather.

ALBERT JOHANNSEN

ENDELL, K., und RIEKE, R. "Ueber die Bildung des Cristobalits aus Quarzglas und ueber seine reversible Zustandsänderung bei 230," *Tschermaks Min. u. Petr. Mitt.*, XXI (1912), 501–12.

ENDELL, K., und RIEKE, R. "Ueber die Umwandlungen des Kieselsäureanhydrids bei höheren Temperaturen," *Zeitschr. anorgan. Chemie*, LXXIX (1912), 239–59.

The authors show that quartz, amorphous silica, and quartz glass change to cristobalite at high temperatures and in the absence of mineralizers.

A. J.

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ENDELL, K., und SMITS, A. "Ueber das System $SiO_2$," *Zeitschr. anorgan. Chemie*, LXXX (1913), 176–84.

A further contribution to the inversion of quartz glass to $\beta$-cristobalite, quartz glass to $\beta$-quartz, and $\beta$-cristobalite to $\beta$-quartz.

A. J.

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ENDELL, K. *Ueber die Umwandlungen der Kieselsäure bei höheren Temperaturen.* Leipzig, 1913. Pp. 6.

An address before the eighty-fourth meeting of the Gesellschaft deutscher Naturforscher und Aertzte zu Münster giving a summary of the author's work on the inversion of $SiO_2$ at high temperatures.

A. J.

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ENDELL, K. "Ueber Granatamphibolite und Eklogite von Tromsö und vom Tromsdaltind," *Centralbl. f. Min., etc.*, 1913, 129–33.

Garnet amphibolite and eclogite from northern Norway are described. A chemical analysis of the former, calculated in the Osann system, gives $a_{1.5}c_{5}f_{13.5}$.

A. J.

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FENNER, CLARENCE N. "The Various Forms of Silica and Their Mutual Relations," *Jour. Washington Acad. Sci.*, II (1912), 471–80.

Shows that either tridymite or cristobalite may, under certain conditions, such as those which induce rapid crystallization, form at tem-

peratures below their inversion points. Either mineral will retain its form when the temperature is reduced. Quartz, however, is probably never deposited at temperatures greater than 870°. The inversion point of quartz to tridymite is 870°+10°, and tridymite to cristobalite 1470°+10°. The $\alpha$–$\beta$ inversion point of quartz at 575° is not questioned.

A. J.

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FLETT, J. S., and HILL, J. B. *The Geology of the Lizard and Meneage*, Mem. Geol. Survey England and Wales, Explanation of Sheet 359. London, 1912. Pp. 280, pl. 15, figs. 10.

The rocks described are serpentines, peridotites, gabbros, dolerites, epidiorites, gneisses, granite gneisses, greenstones, soda granite porphyries, granites, and schists, as well as sedimentary rocks. Many analyses are given, and there are 24 fine heliotypes of rock sections.

A. J.

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FOOTE, W. M. "Preliminary Note on the Shower of Meteoric Stones at Aztec, near Holbrook, Navajo County, Arizona," *Amer. Jour. Sci.*, XXXIV (1912), 437–56, figs. 17.

In the meteoric fall at Holbrook, Ariz., July 19, 1912, over 14,000 stones are recorded, with a total weight of 218,310 grams.

A. J.

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GALPIN, SYDNEY LONGMAN. "Studies of Flint Clays and Their Associates," *Trans. Amer. Ceramic Soc.*, XIV (1912), 301–46.

From geologic occurrences, dehydration tests, and microscopic examination, the author concludes: (1) Flint clays have been formed by the setting and recrystallization of fine-grained, largely colloidal sediments. The products of recrystallization are mainly kaolinite, with minor amounts of hydrated micas. (2) The semi-flint or soft clays have been derived from the flint clays through metamorphism, resulting in a conversion of much kaolinite into hydro-micas. (3) Plastic fire clays have resulted from long weathering of the soft clays. They contain a high percentage of hydro-mica. (4) The change from muscovite through hydrated or hydro-micas to kaolinite may take place without destruction of the original structure, indicating the possibility of an isomorphous series embracing all of these minerals.

A. J.

GOLDBECK, ALBERT T., and JACKSON, FRANK H. *The Physical Testing of Rock for Road Building.* Bull. 44, Office of Public Roads, U.S. Dept. of Agriculture, Washington, 1912. Pp. 96, figs. 20.

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GRATON, L. C., and MURDOCH, JOSEPH. "The Sulphide Ores of Copper. Some Results of Microscopic Study," *Trans. Amer. Inst. Min. Eng.*, New York meeting, Feb., 1913, 741–809.

While this paper is principally of interest to the economic geologist, it is of importance to the petrographer from the authors' work on the determination of ore minerals by means of the microscope. This is a problem which has only recently been attacked, and in the solution of which but little has been done. It opens up a new field to petrographers, and promises to be of great importance in the determination of opaque minerals.

A. J.

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GWILLIM, FARIBAULT, and BARLOW. *Report on the Geology and Mineral Resources of the Chibougamau Region, Quebec.* Quebec, 1911. Pp. 216+viii, pl. 78, figs. 19, maps 2.

Numerous rocks and minerals are described and illustrated. A number of analyses is given.

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HARDER, E. C. "Structure and Origin of the Magnetite Deposits near Dillsburg, York County, Pennsylvania," *Econ. Geol.*, V (1910), 599–622.

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HATCH, F. H., and RASTALL, R. H. *Text Book of Petrology; The Sedimentary Rocks.* London, George Allen & Co. Pp. 525, figs. 60.

While there is a wealth of literature regarding the sedimentary rocks, the processes which produce them, and their metamorphic equivalents, this volume represents the first published attempt, in English, to bring the knowledge of the subject together. About one-third of the book is devoted to the sedimentary rocks, and the balance to the metamorphic processes and the metamorphic derivatives of the sediments. The subjects cementation, metasomatism, contact metamorphism, regional metamorphism, and weathering are included.

Though no classification of the sediments has been generally agreed

upon, the authors group deposits as fragmental, chemical, and organic. The various types of these are described, and much space is devoted to their origin. An attempt is made to present criteria by means of which the terrestrial deposits may be distinguished from each other and from marine deposits. These criteria include the form and size of the grains, and the presence or absence of certain minerals, but, as is pointed out by the authors, there are such insufficient data on many of these points and the exceptions are so numerous that safe conclusions can scarcely be drawn. The absence of mica in wind-blown sand is notable, but this criterion could not confidently be applied to cemented deposits where mica might have been developed by slight metamorphism.

The statement is made that because of variations in the chemical composition of coals "they must have originated under widely different conditions." This is hardly a necessary conclusion, since varying amounts of inorganic matter must have been transported by wind and water into the many basins of accumulation. The analyses of different kinds of coals quoted are neither average nor typical analyses of their types.

The authors seem to accept the idea that the fusion of sediments on a large scale is due to the great pressure of accumulated overlying matter, but it is to be greatly doubted whether fusion on a large scale has ever taken place, although there are undoubtedly many places where local fusion has gone on. The thickness given for the Laurentian gneisses as some 50,000 feet may be the result of complex duplication of beds by faulting and folding.

The geology of the Scottish Highlands, which has been so minutely worked out in recent years, is presented in some detail as an illustration of regional metamorphism.

A final chapter on the systematic examination of the loose detrital sediments is given under the authorship of T. Crook.

Field data and abundant references to geological literature enhance the value of the book and it is well adapted to elementary courses. The figures are numerous and clear.

E. A. STEPHENSON

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IDDINGS, JOSEPH P. "The Petrography of Some Igneous Rocks of the Philippines," *Philippine Jour. Sci.*, V (1910), 155–70.

Describes both plutonic and eruptive rocks. Andesites make up the great bulk of the volcanic rocks of the island, basalts are next in importance, while dacites and rhyolites, so far as known, are rare and occur in

relatively small bodies. Syenite, diorite, quartz diorite, gabbro, peridotite, and granite occur, the latter being rather uncommon. The rocks are given the standard names, no attempt having been made to determine them in the Cross, Iddings, Pirsson, Washington system.

A. J.

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JEVONS, H. STANLEY, JENSEN, H. I., TAYLOR, T. G., and SÜSSMILCH, C. A. "The Geology and Petrography of the Prospect Intrusion." *Jour. and Proc. Roy. Soc. N.S. Wales*, XLV (1911), 445–553.

About 18 miles from Sydney, in the midst of the Wianamatta (Triassic) shales, occurs a massive intrusion of an augite-plagioclase rock. The mass is roughly oval in shape, two miles long by one mile wide, and forms a ring inclosing an isolated area of the shale. Numerous exposures show this shale to be nowhere more than a few feet thick, and the igneous rock is everywhere continuous beneath it. The main rock consists of titaniferous augite 36 per cent, a zonal feldspar 36 per cent, olivine 10 per cent, ilmenite and magnetite 13 per cent, with biotite and apatite as accessories, and analcite secondary. The plagioclase is called an acid labradorite by the authors. Its central portion is labradorite ($Ab_3An_4$), the rim is oligoclase ($Ab_6\ An_1$), and the average composition of the whole, by analysis, $Ab_4An_3$. The authors believe the analcite to have been derived from the feldspar, and not from a pre-existing nephelite. They regard it as distinctly secondary.

Surrounding the central mass of the intrusion is a shell of a very dark, compact, gray rock, having the appearance of basalt. It not only forms the outer zone, but occurs at the contact with the central mass of shale as well, showing that it is actually a mantle around the entire mass. This rock grades into that of the main mass, the size of grain gradually increasing.

The main mass of the Prospect rock has always been called a dolerite in the sense of Teall, Hatch, *et al.*, and not in the German sense, or a diabase in the sense of Harker. The outer zone has been spoken of as basalt or olivine basalt. On account of the association of the rock with nephelite rocks, and the presence of as much as 18 per cent of orthoclase and a little aegirite-augite in some of the segregation veins, the authors regard the rock as a basic differentiation product of an alkali mother magma, wherefore they give to it the name essexite. To the border they give the name pallio-essexite, the prefex being applied by Mr. Jevons to denote the compact envelope of any rapidly cooled igneous rock. In

the Cross, Iddings, Pirsson, Washington system, the rocks are camptonoses; the inner mass a grano-augite-camptonose, the envelope a pitaxi-biaugi-camptonose.

Further, there are described associated pegmatite and aplite veins, and the mode of intrusion is discussed.

ALBERT JOHANNSEN

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JEVONS, H. STANLEY, JENSEN, H. I., and SÜSSMILCH, C. A. "The Differentiation Phenomena of the Prospect Intrusion," *Jour. and Proc. Roy. Soc. N.S. Wales*, XLVI (1912), 111–38.

In this paper the origin of the various segregation veins occurring in the Prospect intrusion is discussed. The authors assume that all have originated *in situ* during the cooling and consolidation of a single magma, which may or may not have been homogeneous when intruded. The paper is divided into two parts. In the first Jevons summarizes the various differentiation hypotheses, and in the second, the differentiation phenomena of the Prospect intrusion are discussed by Jensen and Süssmilch.

A. J.

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JOHANNSEN, ALBERT. *Manual of Petrographic Methods*. New York: McGraw-Hill Book Co., 1914. Pp. xxviii+649, figs. 770.

This publication fills a long-felt want of a comprehensive book in English on petrographic methods.

After a brief introduction on crystallographic principles and on stereographic projection it gives a full treatment of those parts of optical crystallography of value in petrographic research, and the various means of determining the optical constants. For each of the more important properties, methods are given in historic order. Not only are the present standard methods fully described, but those of historic interest are either described or briefly outlined, with references to the original literature, so that one hoping to improve petrographic technique may be saved much unnecessary labor by having placed before him the various schemes that have been tried and later displaced by apparently more satisfactory methods. The discussions are both geometrical and analytical.

The properties of lenses are discussed and the various types of microscopes and accessories are briefly described and illustrated, thus giving the student an idea of the different characteristics of the designs of instruments produced by the various European and American makers.

Methods of specific gravity determinations and of separation of rock constituents are given, including a description of each of the various heavy solutions and melts used for such purposes. Microchemical tests are briefly presented, the treatment being limited to special methods for distinguishing certain particular minerals and groups.

Methods for the study of opaque minerals are but briefly referred to. Considering the growing importance of this part of the subject, it would seem desirable that this section should be expanded, as the author himself remarked in his preface.

The book ends with a discussion of the preparation of thin sections, collecting, filing, and cataloguing of rock specimens and sections, and an appendix of useful mathematical formulas, recipes, etc.

A special feature of the book is the references to the original literature, which are representative and comprehensive even in those parts of the subject which are but briefly treated in the text.

The illustrations are abundant and excellent. Special mention may be made of the beautiful half-tones (after Hauswaldt) of interference figures. And in this connection it may be noted that much credit is due the publishers for the excellent book work—a feature which adds much to the readability and usefulness of the book.

The multiplicity of methods described would probably be confusing to most beginning students, yet the descriptions are presented as far as possible in a simple and elementary way, taking little for granted, and thus by a judicious selection of the articles to be studied, the book could be made use of in an elementary course. Numerous cross-references are helpful in making rapid reference possible to related or explanatory sections.

For a first edition of a book of this character, dealing with numerous details of description, tables, and formulas, it appears to be remarkably free from infelicities or errors of detail in statement or print. With no attempt at completeness, a few may be noted.

P. 20, throughout discussion, $a$ should read $c$ to agree with Fig. 35.

P. 33, article 25, line 10, "If $\alpha$ is constant," read $\omega$ for $\alpha$.

P. 67, the row of figures 113 to 118 should be inverted, the figure at the right being 113.

It would seem desirable to use some such expression as "normal velocity surface" instead of "wave surface" in the discussions of pp. 75 ff., and also pp. 97 and 98. Light passing from the center point may be ideally conceived as actually passing out in the form of the so-called ray surface, but it cannot be imagined as spreading out in the form of

the "wave surface," and this again is confusing to students. The vibration "ellipsoid" of Fig. 131 should of course be "ovaloid."

P. 243, line 1, second paragraph, for "microscope" read "micrometer."

P. 275, next to last line, for figure "370" read "373."

P. 358, $\alpha$ and $\acute{\alpha}$ should read $\theta$ and $\theta'$ (lines 3 and 11).

P. 359, line 2, sin $^2V > K$ should read sin $^2V < K$.

P. 528, in table, fifth column, bottom row "bromoform" should read "iodoform."

It is remarkable, considering recent tendencies, to find so large a general treatise in petrography without an abundance of newly coined terms. The author contents himself with one: melatope, for the spot or "eye" in interference figures representing the emergence of an optic axis.

GEORGE D. LOUDERBACK

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JOHNSTON, JOHN, and ADAMS L. H. "On the Density of Solid Substances with Especial Reference to Permanent Changes Produced by High Pressures," *Jour. Amer. Chem. Soc.*, XXXIV (1912), 563–84.

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JOHNSTON, JOHN, and ADAMS, L. H. "On the Effect of High Pressures on the Physical and Chemical Behavior of Solids," *Amer. Jour. Sci.*, XXV (1913), 205–53.

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KATO, TAKEO. "Ueber die Kordieritführenden Einschlüsse in der Lava aus dem Vulkan Komagataké auf Hokkaido, Japan," *Jour. Geol. Soc. Tokyo*, XIX (1912), 27–37.

The volcano of Komagataké is built up of layers of pyroxene andesite and pumice agglomerate. The chief lava streams are three in number, of which the lower is compact, the second less so, and the upper porous and slaggy and filled with inclusions of the same material and fragments of rhyolite, norite, and cordierite-bearing rock. The three lava streams have similar mineral composition and consist of labradorite, hypersthene, and augite, in a glassy or hyalopilitic groundmass. Olivine occurs in the lower part of the middle flow. The underlying rock of Komagataké consists of late Tertiary tuffites, shales, and diatomaceous earths, and the cordierite in the included fragments has been produced by the metamorphism of the sedimentary rock by the andesite.

A. J.

KATO, TAKEO. "The Tourmaline Copper Veins in the Yakuoji Mine, Nagato Province, Japan," *Jour. Geol. Soc. Tokyo*, XIX (1912), 69–88.

The copper veins of the Yakuoji mine occur at the contact between a monzonite stock and Paleozoic sediments, 3 kilometers east of Oda in the province Nagato. Near the contact with the eruptive rock the metamorphosed sandstones and sandy slates are traversed by innumerable minute veinlets consisting chiefly of chlorite and rare tourmaline. The latter mineral occurs in irregular patches and is considered by the author as replacing feldspar grains, partially or entirely.

A. J.

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KILLIG, FRANZ. *Das Korund- und Paragonitvorkommen am Ochsenkopf bei Schwarzenberg in Sachsen*. Inaug. Diss., Greifswald, 1912.

The corundum of the Ochsenkopf is a product of regional metamorphism and was derived, contemporaneously with the formation of the surrounding phyllite, from an aluminium rich sediment. The paragonite is not an alteration product of the corundum but has been derived independently from the normal phyllite.

A. J.

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KOLDERUP, CARL FRED. "Sogneskollens og Bremangerlandets granodioriter," *Bergens Museums Aarbok*, 1911, Nr. 18, pp. 30.

Describes various granodiorites. The rock from Sogneskollen, in western Norway, is post-Silurian in age. It consists of about 70 per cent feldspar, predominantly oligoclase, with some microperthite, microcline, and orthoclase; 23½ per cent quartz, 6 per cent biotite, and some epidote, garnet, titanite, pyrite, and sericite. The granodiorite of the Island of Svano occurs in the form of a dike. It contains 55⅔ per cent plagioclase (oligoclase-albite and albite), 12 per cent orthoclase and microcline, 23 per cent quartz, 9 per cent muscovite and epidote, and one-third of 1 per cent zircon, apatite, and titanite. The Bremangerland rock consists of 62 per cent feldspar which is entirely andesine, oligoclase, and albite. No orthoclase occurs although a little $K_2O$ is shown by the analysis. Quartz makes up 27¾ per cent of the rock, biotite 9 per cent, magnetite two-thirds of 1 per cent, and pyrite one-third of 1 per cent. This rock cuts the Silurian strata and occurs in fragments in the Devonian. Analyses are given of all of the rocks.

A. J.

KOLDERUP, CARL FRED, og OTTESEN, P. O. "Utsires fjeldbygning og bergarter," *Bergens Museums Aarbok*, 1911, Nr. 17, pp. 21.

Utsire is a small island off the west coast of Norway. About four-fifths of the rock of which it is composed is gabbro, and one-fifth is "granodiorite." A small amount of gneiss was found. An analysis of the "granodiorite" shows but 0.25 per cent of $K_2O$, and on the mechanical separation of the constituents by means of heavy solutions, no orthoclase was found, the constituents being 50 per cent plagioclase (labradorite 7 per cent and oligoclase 43 per cent), 42 per cent quartz, 8 per cent hornblende, and accessory biotite, iron minerals, and garnet. The rock would better be called a quartz rich quartz diorite. A. J.

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KOTO, B. "On nephelite-basalt from Yingé-men, Manchuria," *Jour. Coll. Sci., Imp. Univ. Tokyo*, XXXII (1912), Art. 6, pp. 14, pl. 2.

This is the first recorded occurrence of nephelite basalt in the Japanese-Korean-Chinese region. It is found in the Yingé-men area, forming low hills, and was probably poured out from the junction between the granite country rock and the overlying Cambrian formation. Its age was not determined. The rock is megascopically porphyritic with minute olivine phenocrysts. Under the microscope its texture is nearly holocrystalline, a very small amount of a brownish, granulated, or fibrous base occurring. The minerals, in the order of their abundance, are: titanaugite, magnetite and titaniferous magnetite, nephelite (30 per cent), and olivine (15 per cent). Picotite is an accessory. Neither feldspar nor apatite occurs. According to the quantitative system of Cross, Iddings, Pirsson, and Washington the rock is a shonkinose-monchiquose, the norm giving 45.5 per cent feldspar, 11.9 per cent nephelite, 23 per cent diopside, 1.4 per cent olivine, 7.4 per cent magnetite, 5.5 per cent ilmenite, and 1.0 per cent apatite. A. J.

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KRAUS, EDWARD H. "Die Aenderungen des optischen Axenwinkels im Glauberit mit der Temperatur," *Zeitschr. f. Kryst.*, LII (1913), 321–26.

So long ago as 1829 Brewster showed that the optic axial angle of glauberite was changed with change of temperature. Kraus shows that the mineral is uniaxial for sodium light at 42°.9 and for lithium light at 51°.8. The curves show that, like gypsum, with increasing temperature the angle becomes less and less until the zero value is reached, after which increasing temperature enlarges it. A. J.

# *Reviews*

"The Wisconsin Drift Plain in the Region about Sioux Falls, South Dakota." By J. Ernest Carman. *Proc. Iowa Acad. Sci.*, XXVI (1913), 237–49.

It sometimes happens that questions of no great moment in themselves—and these chiefly local—come to play a more conspicuous part in the literature of a science than their real importance warrants simply because someone has seen fit to emphasize them unduly and has made them the ground of unwarranted impressions of the delinquencies of predecessors who kept them more nearly in their proper proportions. This paper of Carman's is an appropriate contribution to the geology of a corner of Iowa and of the adjacent regions, and is fittingly published in the *Proceedings of the Iowa Academy of Sciences*. In addition to this appropriateness and local value, it acquires some general interest as an antidote to impressions less well founded and less appropriately given to the scientific public. The question chiefly discussed has so much of importance as may attach to the precise limits to which the Wisconsin drift extended in the region named and to local phenomena incidental to this. To the general student of geology it is of little moment whether a given ice advance stopped at a particular line or went a few miles farther, if no special significance is attached to the precise extension and localization. In the case in hand, it appears that some three decades ago Chamberlin and Todd, as a part of extensive reconnaissance work intended to outline the essential features of the Wisconsin ice invasion, mapped and described the approximate border of the Wisconsin drift in the Sioux Falls–Canton region of southeast Dakota, that later they introduced slight modifications of the original mapping, and that Wilder, of the Iowa Survey, introduced other variations, as did also some others, none of which had more than local value. Perhaps the only feature of general interest was the slight lobation of the glacier implied by the border of this drift, in which all these were agreed. Shimek, however, in a paper read before the Geological Society of America and printed in *Bull. G.S.A.*, XXIII (1912), 125–54, made it appear that these differences were of a more serious order and summed up his "more important conclusions" with dogmatic impressiveness (p. 154). It now appears

from Carman's careful paper that the earlier views were the more nearly correct, and that the earlier authors took views of the value of the features in question more nearly proportionate to their intrinsic importance. Carman seems, therefore, to have performed a distinct service in contributing to the restoration of a more judicious, as well as more judicial, evaluation of the field evidence of the region and of the views that may be best entertained respecting it. C.

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*Textbook of Paleontology.* Edited by CHARLES R. EASTMAN. Adapted from the German of KARL A. VON ZITTEL. 2d ed. Vol. I.

Since the appearance of the first edition of Eastman's Zittel in 1900, this work has been the standard textbook of invertebrate paleontology in all American colleges and universities, and this new edition will be welcomed enthusiastically by all teachers and students of the subject. In the preparation of the present edition, as was also the case with the earlier one, the editor has had the collaboration of many of the leading American specialists in the field of invertebrate paleontology, as well as several European investigators. The work is not a translation of the latest German edition of Zittel; the several chapters have been thoroughly revised or entirely rewritten, bringing the matter up to date in a most satisfactory manner. Were it not that the same illustrations are used for the most part in both the German and the American editions, large portions of the volume would scarcely be suspected of having any relation whatsoever with the original Zittel, although the scope and general treatment is modeled after the well-known German textbook.

It is not worth while, in this place, to enter upon a discussion of the details of the changes in classification, and the additions which have been incorporated in this edition, but the wonderful progress in our knowledge of the extinct invertebrates which has gone forward since the beginning of the century is all reflected in this book.

S. W.

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*Petroleum and Natural Gas in Oklahoma.* By L. C. SNIDER. Pp. 196, figs. 37, pls. 4. Oklahoma City, 1913.

This book is intended to give to those interested a comprehensive review of the petroleum and natural gas industry in Oklahoma. Methods of prospecting are briefly outlined, the geology of the state is described with special reference to favorable points for the accumulation of oil,

and detailed description of the known productive oil fields is given. Supplementing this material are special chapters on the character of the oils, and the methods of transporting and refining them. A review o conditions by counties completes the volume, which should be of much service to those interested in oil, especially in Oklahoma.

A. D. B.

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*The Examination of Prospect.* By C. GODFREY GUNTHER. New York: McGraw-Hill Book Co., 1913. Pp. 222; 79 figs. $2.00 net.

A small handbook of mining geology. The first chapter is devoted to mining examinations proper, while succeeding chapters deal with the geologic features of ore deposits, with examples drawn from a large number of localities. The book is well illustrated with diagrams taken from geologic reports and with a few photographs. It should prove a valuable book for the geologist in the field, where no access to the original reports is to be had. The subject-matter, though brief, seems to be well organized and carefully condensed. The work is bound uniformly with the publishers' series of field handbooks in flexible leather.

A. D. B.

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